PB-240 566

AIR POLLUTION: GUIDELINES TO ASSESSMENT OF AIR QUALITY (REVISED), SOx, TSP, CO, HC, NOx, AND OXIDANTS

NATO Committee on the Challenges of Modern Society

Prepared for:

Environmental Protection Agency

October 1972

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	PB 240 566

4. Title and Subtitle
Air Pollution, Guidelines to Assessment of Air Quality (Revised) SOx, TSP, CO, HC, NOx and Oxidants.

5. Report Date
October 1972

6.

7. Author(s)

8. Performing Organization Rept. No. 6

9. Performing Organization Name and Address
NATO Committee on the Challenges of Modern Society, 1110 Bruxelles, Brussels, Belgium

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
Office of Air and Waste Management, Environmental Protection Agency, Washington, D. C. 20460

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

17. Key Words and Document Analysis. 17a. Descriptors
airpollution
air quality assessment

17b. Identifiers/Open-Ended Terms

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

PRICES SUBJECT TO CHANGE

17c. COSATI Field/Group

18. Availability Statement Available from NTIS	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 310
	20. Security Class (This Page UNCLASSIFIED	22. Price 9.25 / MF 2.25

GUIDELINES TO ASSESSMENT OF AIR QUALITY (Revised)

SOx, TSP, CO, HC, NOx and Oxidants

A Report by the NATO/CCMS
Air Pollution Pilot Study

OCTOBER, 1972

OTHER NATO/CCMS AIR POLLUTION PUBLICATIONS

Technical Report of the Conference on Low Pollution Power Systems Development, N.4

Proceedings of the Second Meeting of the Expert Panel on Air Pollution Modeling, N.5

Air Quality Criteria for Sulfur Oxides, N.7*

Air Quality Criteria for Particulate Matter, N.8*

Air Quality Criteria for Carbon Monoxide, N.10*

*Also avaliable in French

These documents may be obtained from the NATO Committee on the Challenges of Modern Society, 1110 Bruxelles, Brussels, Belgium, or from the Air Pollution Technical Information Center, Office of Air Programs, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, U.S.A. (English only).

RESOLUTION

As a submission of the NATO Committee on the Challenges of Modern Society (CCMS) Pilot Study on Air Pollution, the earlier version of this document and the documents "Air Quality Criteria for Sulfur Oxides" and "Air Quality Criteria for Particulate Matter" were presented before the Fifth Plenary Session of the CCMS in November, 1971 with a resolution declaring the intent of the Plenary to adopt the documents and the systems methodology of air quality assessment outlined in the Guidelines as official NATO documents and methodology. The resolution was adopted by the Plenary.

On January 20, 1972, the North Atlantic Council met and took up the question of the Air Pollution resolution. The resolution, the text of which follows, was adopted by the Council:

> *It has been recognized that air pollution is one of our major environmental issues which requires resolution by the members of the NATO Community, as well as others, on an individual and collective basis. The results of the three assessment studies reinforce the concept of utilizing a comprehensive systems approach for air quality management. The evaluation of the impact has been delineated in the guidelines document and has been verified through application by the pilot and co-pilot countries. The criteria documents on sulfur oxides and particulates provide the scientific basis against which the impact on health and welfare for existing and*

future conditions can be assessed. The control technology documents, when completed, will allow for the national development of control strategies for alleviating the near-term problems as well as projected future needs.

Based on the availability of those tools for development of long-term air quality management strategies, be it resolved that all member nations will:

(1) Take cognizance of the need for dynamic efforts and maintaining the quality of the air;

(2) Endearvor to use, where appropriate for setting up national air quality management programs, the systems methodology generated by the CCMS Pilot studies; and

(3) Promote cooperation among members when air pollution problems are common to national boundaries.

GUIDELINES TO ASSESSMENT OF AIR QUALITY

PREFACE 1

INTRODUCTION 6

EMISSIONS INVENTORY 8

- I. Introduction 8
- II. Air Pollution Sources 9
  - A. Source Categories 9
  - B. Classification of Sources 10
  - C. Requirements for Inventory Data 11
- III. Inventory Methods 11
- IV. Survey Procedure 15
  - A. Inventory Design 17
  - B. Collection of Basic Data 18
  - C. Calculation of Emissions 21

AIR QUALITY MONITORING 26

- I. Role of Monitoring in Assessments 26
- II. Monitoring Systems 26
  - A. Fixed Versus Mobile Sampling 27
  - B. Continuous Versus Integrated Sampling 27
- III. Selection of Instrumentation and Methods 28
  - A. Sulfur Dioxide 29
  - B. Total Suspended Particulates 31
  - C. Carbon Monoxide 33
  - D. Hydrocarbons 34
  - E. Oxidants 35
  - F. Nitrogen Dioxide 36

G. Laboratory Requirements 37

IV. Number and Location of Sampling Sites 38

V. Sampling Frequency and Duration 40

VI. Design of Data Processing System 44

VII. Operation of an Air Monitoring Network 45

VIII. Reduction and Interpretation of Data 48

METEOROLOGICAL MEASUREMENTS 53

I. Introduction 53

II. Instrumentation and Techniques 53

III. Supplemental Stations 55

AIR QUALITY MODELING 58

PROJECTIONS OF AIR QUALITY 64

I. Introduction 64

II. Emission Projections 64

APPENDIX A

ASSESSMENT OF AIR QUALITY IN ANKARA, TURKEY

INTRODUCTION A-1

DESCRIPTION OF STUDY AREA A-4

SOURCES AND EMISSIONS A-9

  I. Introduction A-9

  II. Inventory Procedure A-11

    A. Fuel Combustion in Stationary Sources A-12

    B. Fuel Combustion in Mobile Sources A-16

    C. Solid Wastes A-18

    D. Industrial Processes A-18

  III. Results A-19

    A. Stationary Fuel Combustion A-19

    B. Mobile Fuel Combustion A-22

    C. Solid Waste A-26

    D. Industrial Processes A-26

    E. Seasonal and Geographic Distribution of Emissions .. A-29

AIR QUALITY MONITORING A-40

  I. Introduction A-40

  II. Past Air Quality Data A-41

  III. Network Design A-42

    A. Equipment and Methods A-42

    B. Sampling Network A-50

    C. Sampling Period and Frequencies A-54

  IV. Sampling Operation A-54

    A. Implementing the Monitoring Network A-54

B. Operation of the Network A-56
C. Data Validation and Reduction A-57
V. Results A-58
A. Initial Assessment of SO_2 and TSP A-61
B. Sulfur Dioxide and Suspended Particulates - 18 Months of Data ... A-70
C. Phase II Pollutants A-76
METEOROLOGICAL MEASUREMENTS A-81
I. Introduction A-81
II. Average Meteorological Conditions A-81
A. Wind Flows A-81
B. Mixing Height A-82
C. Atmospheric Stability A-82
D. Temperature A-85
III. Comparison with Meteorological Measurement of Winter 1970/1971 ... A-87
AIR QUALITY MODELING A-91
I. Introduction A-91
II. Procedure A-91
III. Results A-98
PROJECTS OF AIR QUALITY A-105
I. Introduction A-105
II. Estimation of Emissions A-106
A. Expected Growth and Development A-106
B. Procedure for Calculating Emissions A-108
C. Results A-111
III. Projection of Air Quality A-115
IV. Application of Control Tatic A-121

LIST OF FIGURES

Figure		Page
1	Systems Diagram for Air Quality Management	3
2	Procedure for Assessment of Air Quality	6
3	Emission Inventory Techniques	12
4	Fuel Comsumption Questionnaire	20
5	Process Emissions Questionnaire	22
6	Relationship Between Minimum Number of Stations and Region Population	39
7	Process Chart for Analysis and Projection of Air Quality	61
A-1	Ankara, Turkey, and Its Relationship to Surrounding Areas	A-5
A-2	1969 Population Densities in Ankara	A-6
A-3	Ankara Emission Inventory Grid System	A-10
A-4	Emissions of Sulfur Oxides in the Ankara Study Area by Season and by Various Source Categories	A-30
A-5	Emissions of Particulates in the Ankara Study Area by Season and by Source Category	A-31
A-6	Annual Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides in the Ankara Study Area by Source Categories	A-32
A-7	Location of Major Point Sources in the Ankara Area	A-33
A-8	Sulfur Oxide Emission Densities in Ankara, Yearly Average	A-34
A-9	Particulate Emission Densities in Ankara, Yearly Average	A-35
A-10	Carbon Monoxide Emission Densities in Ankara, Yearly Average	A-37

A-11 Hydrocarbon Emission Densities in Ankara, Yearly Average A-38

A-12 Nitrogen Oxides Emission Densities in Ankara, Year Average A-39

A-13 High Volume Air Sampler A-44

A-14 Integrated Sulfur Dioxide Sampler A-46

A-15 Continuous Coulometric Analyzer for Sulfur Dioxide .. A-47

A-16 Flame Photometric Instrument for the Continuous Analysis of Total Sulfur A-49

A-17 Location of Monitoring Stations in Ankara A-51

A-18 Recording Form for Continuous SO_2 Data A-59

A-19 Recording Form for 25-Hour Average Concentrations of SO_2 .... A-60

A-20 Total Suspended Particulates Concentrations, Ankara, October 1970-March 1971 .... A-64

A-21 SO_2 Concentrations, Ankara, October 1970-March 1971 . A-65

A-22 Percent of Days U. S. Primary 24-Hour Standard for SO_2 and Particulates was Exceeded at Each Monitoring Station, October 1970-March 1971 .... A-66

A-23 Monthly Variation in Concentrations of SO_2 and TSP (October-March) Network Composite, Highest Station (Ulus) and Lowest Station (Esenboga) A-68

A-24 Daily Concentrations of SO_2 and Suspended Particulate at Station No. 7, Ulus A-69

A-25 Variation in Hourly SO_2 Concentrations - Three Month Average (December-February) A-71

A-26 Frequency Distribution of Hourly Concentrations, December-February A-72

A-27 Hourly Variability in CO Concentrations, February 1972 .... A-79

A-28 Percent Frequency of Wind Speed and Direction for Various Averaging Times A-83

A-29 Average Monthly Mixing Height and Transport Wind Speed for Ankara, 1964-1968 .... A-84

A-30 Frequency of Occurrence of Stability Class by Hour (3-Hour Data, 1964-1968) A-86

A-31 Winter 1970, Wind Rose for Ankara, Turkey A-88

A-32 Mean Wind Differences Between the Meteorological Office and Hygiene School A-89

A-33 Correlation of Predicted and Observed SO$_2$ Concentrations Using Gaussian Plume Dispersion and Uniform 24-Hour Emission Rates A-93

A-34 Correlation of Predicted and Observed SO$_2$ Concentrations Using Gaussian Plume Dispersion and Variable 24-Hour Emission Rates A-93

A-35 Correlation of Predicted and Observed SO$_2$ Concentrations Using "Box Model Diffusion" and Variable 24-Hour Emission Rates A-94

A-36 Correlation of Predicted and Observed TSP Concentrations Using Gaussian Plume Dispersion and Uniform 24-Hour Emission Rates A-96

A-37 Correlation of Predicted and Observed TSP Concentrations Using Gaussian Plume Dispersion and Variable 24-Hour Emission Rates A-97

A-38 Correlation of Predicted and Observed TSP Concentrations Using "Box Model Diffusion" and Variable 24-Hour Emission Rates A-99

A-39 Mean Annual Sulfur Dioxide Levels in Ankara Predicted by Model A-100

A-40 Mean Winter Sulfur Dioxide Levels in Ankara Predicted by Model A-101

A-41 Mean Annual Suspended Particulate Levels in Ankara Predicted by Model A-103

A-42 Mean Winter Suspended Particulate Levels in Ankara Predicted by Model A-104

A-43 Ankara Population Projections A-107

A-44 Emissions Projections, Ankara, Turkey A-112

A-45 Mean 1990 Annual Sulfur Dioxide Levels in Ankara Predicted by Model A-116

A-46 Mean 1990 Annual Particulate Levels in Ankara Predicted by Model A-117

A-47 Mean 1990 Winter Sulfur Dioxide Levels in Ankara Predicted by Model A-119

A-48 Mean 1990 Winter Suspended Particulate Levels in Ankara Predicted by Model A-120

A-49 Projected Emissions; Assumes the Use of 1% Fuel and Coal Briquetting for Home Heating by 1980 .... A-122

A-50 Mean 1990 Annual Sulfur Dioxide Levels in Ankara Predicted by Model with Control Strategy of 1% Sulfur . A-123

A-51 Mean 1990 Annual Suspended Particulate Levels in Ankara Predicted by Model with Control Strategy of Briquetting of Coal for Household Heating A-124

LIST OF TABLES

Number Page

1 Summary of Emission Inventory Techniques 16

2 Methods for Measuring Sulfur Dioxide 30

3 Methods for Measuring Suspended Particulates 32

4 Relationship of Sampling Frequency to the Percent Deviation From the True Mean 42

5 Relationship of Sampling Frequency to the Coefficient of Variability of Sample Mean Values 43

6 Characteristics of Urban Dispersion Models for Stable Pollutants 60

A-1 Employment Characteristics of Ankara A-8

A-2 Sources of Data for the Ankara Emissions Inventory A-13

A-3 Air Pollutant Emissions From All Sources in the Ankara Study Area, 1969 .... A-20

A-4 Consumption of Fuels in Stationary Sources for the Ankara Study Area, 1969 .... A-21

A-5 Fuel Qualities for the Ankara Study Area, 1969 .... A-23

A-6 Emissions from Fuel Combustion in Stationary Sources in Ankara, 1969 .... A-24

A-7 Air Pollutant Emissions from Mobile Sources in Ankara, 1969 .... A-25

A-8 Air Pollutant Emissions from Solid Waste Disposal, 1969 .... A-27

A-9 Air Pollutant Emissions from Industrial Processes, Ankara, 1969 .... A-28

A-10 Location and Description of Sampling Sites A-52

A-11 Total Suspended Particulate and Sulfur Dioxide Average Concentrations in Ankara, October 1970-March 1971 ..... A-62

A-12 Sulfur Dioxide Average Concentrations in Ankara October 1970-March 1972 .... A-73

A-13 Total Suspended Particulate Average Concentrations in Ankara, October 1970-March 1972 .... A-74

A-14 Carbon Monoxide, Total Hydrocarbons, Ozone and Nitrogen Dioxide Concentrations in Ankara, 1971-1972 . A-77

A-15 Average Monthly Temperature (°C), 1964-1968 .... A-85

A-16 Distribution of Working Population in Ankara A-109

A-17 Expected Travel Needs for Ankara A-109

A-18 Comparison of 1969 and 1990 Air Pollutant Emissions, Ankara, Turkey A-113

A-19 Summary of Air Pollutant Emissions in the Ankara Study Area, 1990 .... A-114

PREFACE

The North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society" (CCMS) at the November 1969 meeting of the North Atlantic Council. The CCMS was charged with developing meaningful environmental and social programs that complement other international programs, and with showing leadership, first in solution of existing problems and, second, in development of long-range goals for environmental protection in the NATO sphere of influence and in other countries as well. The Pilot Study on Air Pollution is one of several pilot projects initiated by the CCMS at its inaugural meeting in December 1969. The United States (Environmental Protection Agency) is the pilot nation in the air pollution study, with the Federal Republic of Germany (Federal Ministry of Interior) and Turkey (Scientific and Technical Research Council) as co-pilot nations.

The Pilot Study on Air Pollution is an action program designed to demonstrate and encourage the utilization of existing knowledge for the development of long-range air quality management programs. It entails the demonstration of the systems approach to air quality management. The systems approach consists of several major elements, all of which are essential to the objective of optimally enhancing air quality:

(1) designation of area boundary

(2) assessment of air quality

(3) promulgation of criteria

(4) assessment of control technology

(5) establishment of air quality standards

(6) development and implementation of abatement and control strategies

Several supporting activities are required:

(1) research on air pollution effects

(2) research and development of control technology

(3) comprehensive surveillance

The methodologies which may be utilized in carrying out the functions of the first four elements of the system have universal application, while the standard setting and implementation elements must be conducted by the states or countries undertaking air quality management programs.

Four tasks, initiated in the CCMS Pilot Study, direct themselves to the following elements of the system:

(1) designation of area boundary,

(2) assessment of air quality,

(3) development and promulgation of criteria, and

(4) assessment and promulgation of control technology.

(These elements are shown in bold type in Figure 1.) The Study is divided into several phases. Phase I encompassed these tasks for only two pollutants--sulfur oxides and particulate matter; Phase II assessed the automobile-related pollutants, e.g., carbon monoxide, hydrocarbons, total oxidants, and nitrogen oxides.

Tasks I and II deal primarily with the air quality assessment element of air quality management. The Working Group* selected Ankara,

---

*The Working Group on Air Pollution consists of one representative each from the pilot and co-pilot countries, viz., the United States, Federal Republic of Germany, and Turkey.

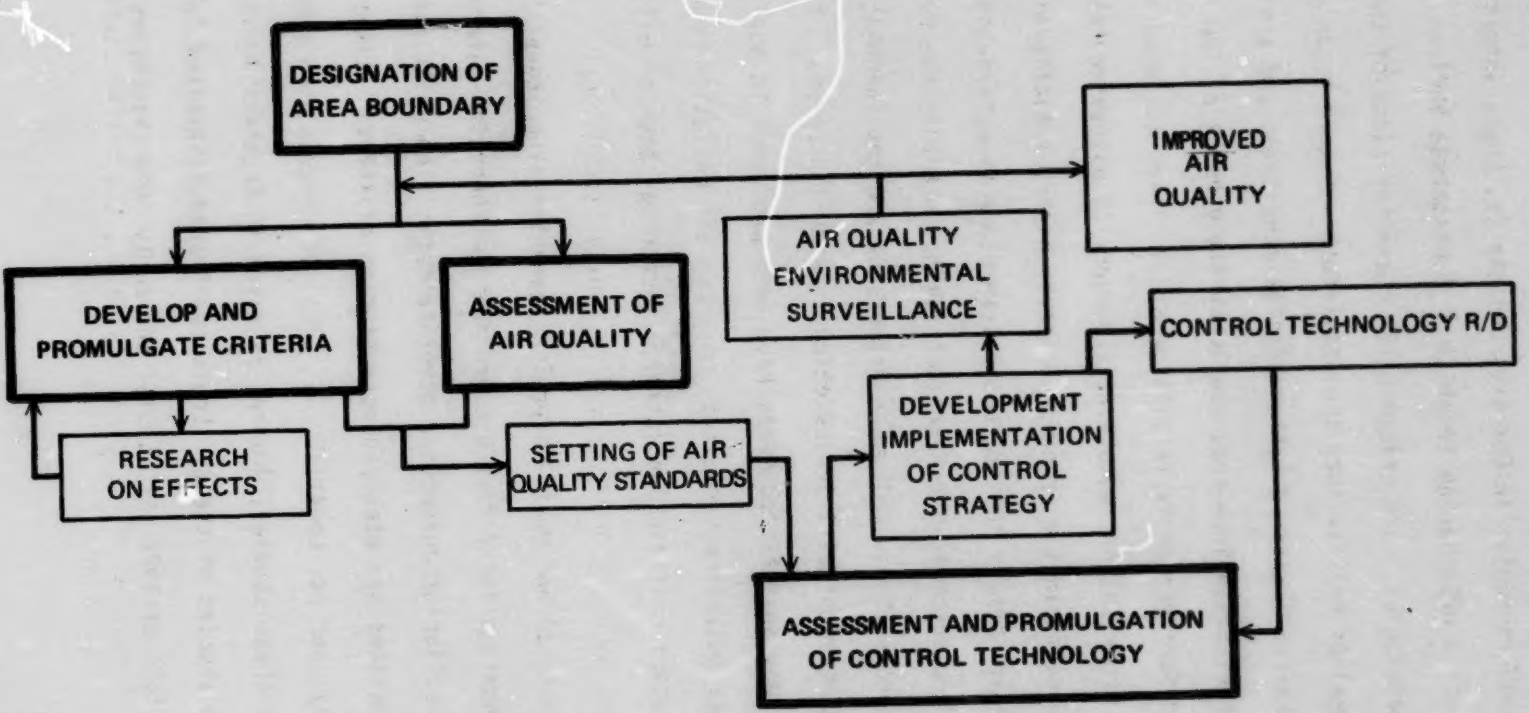

DESIGNATION OF AREA BOUNDARY
IMPROVED AIR QUALITY
DEVELOP AND PROMULGATE CRITERIA
ASSESSMENT OF AIR QUALITY
AIR QUALITY ENVIRONMENTAL SURVEILLANCE
CONTROL TECHNOLOGY R/D
RESEARCH ON EFFECTS
SETTING OF AIR QUALITY STANDARDS
DEVELOPMENT IMPLEMENTATION OF CONTROL STRATEGY
ASSESSMENT AND PROMULGATION OF CONTROL TECHNOLOGY

FIGURE 1. Systems Diagram for Air Quality Management

Turkey; the Frankfurt region in Germany; and the St. Louis interstate area in the U. S. as urban areas in which to demonstrate various assessment methodologies. The unique urban characteristics of these areas lend themselves well to such a pilot effort. Ankara is an urban center with rather well-defined meteorological conditions and a single predominant type of pollution--that caused by the burning of low quality fuels. The Frankfurt region is very large and is in an advanced state of multi-center urbanization, with a wide variety of dispersed heavy industry. Meteorology in the Frankfurt area is highly variable with respect to space and time. The St. Louis interstate area, which is similar in size and scope to the Frankfurt region, exhibits the transboundary aspects of air pollution dispersion and the inherent problems associated with multi-jurisdictional control programs. As a result of this study several documents have been produced; in addition to this assessment guideline, documents on urban air pollution modeling techniques, pollutant criteria, and control technology have or will be issued.

Further, bilateral and multi-lateral agreements may be developed to establish mechanisms for direct cooperation in exchanging data and knowledge on low-pollution automobile power systems. The guidelines and the recommendations are based on case studies of Ankara, Turkey; Frankfurt, Germany; and St. Louis, U. S. Detailed descriptions and results of one of these studies, Ankara, is given in Appendix A. Appendices B and C, the case studies of the St. Louis and Frankfurt Regions, will be published in the fall of 1972 (St. Louis) and early 1973 (Frankfurt).

It is hoped that this guideline document, as well as subsequent documents, will assist those countries with current and projected air pollution problems in developing systematic and effective air quality management programs. Further, through such a uniform approach, the format is established for cooperation among nations in their approach to evaluating and preventing air pollution impact on our environment, both on a regional and global scale.

INTRODUCTION

The general procedure for assessing air quality, illustrated in Figure 2, is predicated on the application of mathematical diffusion models for estimating existing and future ambient air quality levels. The procedure consists of four subtasks: (1) collection of data on emissions, meteorology, and air quality; (2) verification of the model using measured air quality; (3) forecasting of future emissions; and (4) estimation of future air quality.

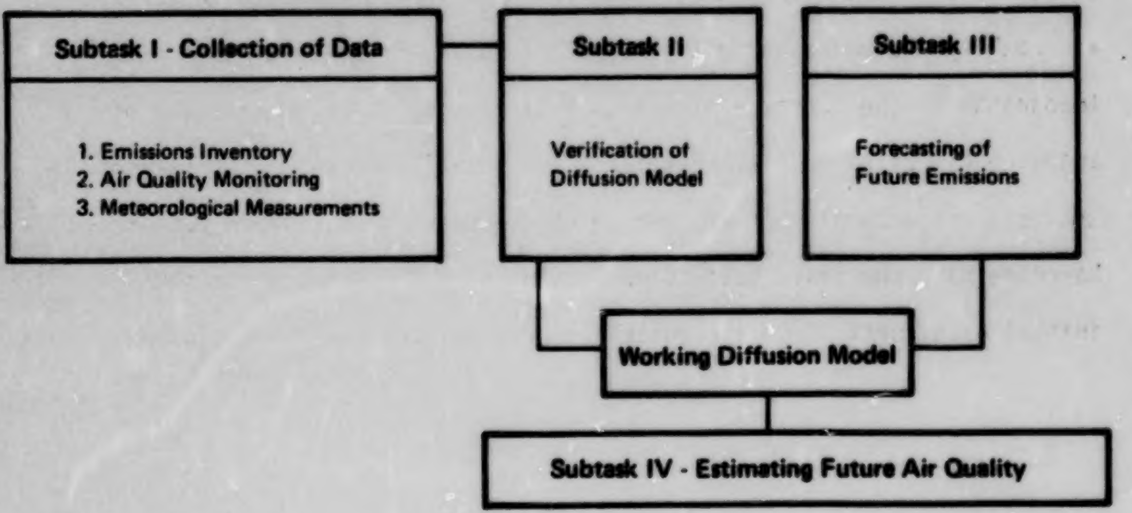

Subtask I - Collection of Data
1. Emissions Inventory
2. Air Quality Monitoring
3. Meteorological Measurements
Subtask II
Verification of Diffusion Model
Subtask III
Forecasting of Future Emissions
Working Diffusion Model
Subtask IV - Estimating Future Air Quality

FIGURE 2. Procedure for Assessment of Air Quality.

The remainder of this document describes the procedures used in assessing air quality in urban areas: collection of data on emissions, meteorology, and air quality; and use of mathematical models in estimating present and future air quality levels. Recommendations based on the case studies are given. Included are estimates of the types of resources that are needed to carry out such studies.

Although ideally the comprehensive assessment of any pollutant requires the full accomplishment of the 4 subtasks, in certain cases this may not be feasible or practical. For instance the techniques for modeling reactive pollutants such as hydrocarbons, oxides of nitrogen, and ozone are still in developmental stages. For these the estimation of future air quality may need to be based on an extrapolation of existing air quality and emissions data. In other cases irregularities in topography or the shortage of air quality data may preclude the use of adequate diffusion models. Similarly the detail with which the various subtasks are accomplished are very much dependent on available resources. Nevertheless, the basic guidelines provide a good framework for the initial assessment of an air pollution problem, and must be followed.

EMISSIONS INVENTORY

I. Introduction

Emissions, air quality, and meteorological data provide the basic information for understanding an area's air pollution problem. This section of the report describes the types of emissions data needed, and how they can be obtained.

The accounting of air pollutant sources and their related emission rates for a given area is defined as an emissions inventory. Although many different procedures are available for compiling an emissions inventory, all of them depend on the use of average emission factors, since it is impractical to measure continuously, or even periodically, the discharges of pollutants into the atmosphere from all sources. Emission factors are formulated for classes of polluting sources, such as automobiles, household furnaces, and cement plants. This is done by measuring emissions from a number of individual sources in each class and then deriving a statistical average to be applied to that class in conjunction with an emission index, such as fuel consumption or production rate. By this means, emission factors have been formulated for most of the major types of sources.

Emissions data are used in estimating present as well as projected pollutant concentrations in the air. This can be done through the use of air quality models. Additionally, inventory data are required in almost all facets of air pollution abatement programs. They are used as a guide to metropolitan planning activities, in the design of sampling programs, in enforcement of regulations, and in development of control strategies.

II. Air Pollution Sources

A. Source Categories. The sources of pollution [illegible] typically classified into the following five categories: (1) fuel combustion in stationary sources, (2) fuel combustion in mobile sources, (3) industrial processes, (4) solid waste disposal, and (5) evaporation of organic substances. Other sources of pollutants, such as agricultural burning and wind-blown dust, do not fall into the categories listed, but may be significant in some areas.

(1) Fuel combustion in stationary sources. The first category includes all facilities where fuels are burned to provide either space or process heating. All fuels--coal, coke, fuel oil, gas, and wood--contribute in varying degrees to total emissions. In most areas, the burning of these fuels accounts for the majority of sulfur oxide and particulate emissions. Sources in this category can be further subdivided according to the type of consumer: (1) steam-electric power plants, (2) industrial facilities, (3) houses and apartment buildings, and (4) commercial, institutional, and governmental buildings.

(2) Mobile sources. This category includes road vehicles, vessels, trains, and aircraft. The fuels of primary concern are gasoline and diesel fuel used by motor vehicles; diesel oil, and coal burned in locomotives and vessels; and aviation fuels used in aircraft. Carbon monoxide, oxides of nitrogen; hydrocarbons, and particulates (e.g., diesel smoke, lead, etc.) are pollutants of primary interest from this category

of sources.

(3) Industrial processes. This category includes all facilities--factories and shops--that generate pollutants during the manufacture or handling of products, other than the pollutants emitted from the use of fuels. In this context, industrial facilities are included in both categories--stationary fuel combustion and industrial processes.

(4) Disposal of solid waste. This category consists of the incineration or open burning of solid waste which can be a significant source of pollution. Such burning may take place either in large central facilities, such as municipal incinerators and open-burning dumps, or at individual residences, factories, or shops.

(5) Evaporation of organic substances. Included in this category is the evaporation of gasoline, paints, and dry cleaning solvents.

B. Classification of Sources. The multitide of sources in urban areas can be further classified according to emission rates. Sources that individually contribute significant amounts of pollutants deserve special attention; in most inventories these are considered separately as point sources. Typically these include power-generating stations, central incinerators, and large industrial concerns such as steel mills, cement plants, and refineries. It is important to note that in some cases a point source may consist of a multitude of points of emission, i.e., numerous stacks serving one factory or storage tanks and other facilities in a large refinery. In most cases these are considered as single points of emission for that plant. Sources that individually do not contribute significant quantities of pollutants are considered jointly as area sources; typical of these are automobiles, houses, and small industries.

C. Requirements for Inventory Data. The intent of an emissions inventory is to determine (1) quantities of air pollutants emitted, (2) geographical locations and characteristics of sources and emissions, and (3) variability of emissions with respect to time. Emissions are typically reported in terms of weight per unit time, such as tons per year or grams per hour. Sources are identified and located through the use of a grid coordinate system by denoting the exact coordinates for point sources and grouping area sources into grids.

Emission rates are time-dependent. They vary not only from year to year because of changing levels of activity, but also seasonally, daily, and hourly. Seasonal variability is primarily due to space heating requirements and to emissions from industries affected by temperature or other weather conditions. Typically, emissions data are reported on annual or seasonal basis, such as tons per year or tons per average winter day.

III. Inventory Methods

Several emission inventory techniques can be utilized to delineate the sources and emissions of an area. These techniques differ in the degree of detail provided, as well as the manner in which the data are collected. Similarly each technique has typical attendant requirements for time, personnel, and budgetary resources.

Several general types of inventories are depicted in Figure 3.

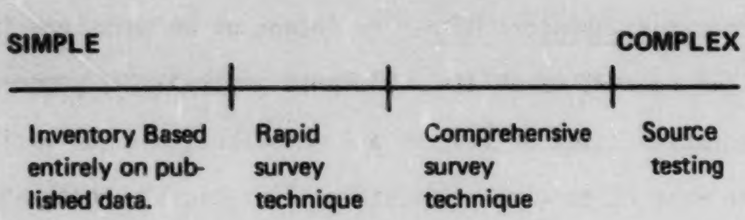

SIMPLE
COMPLEX
Inventory Based entirely on published data.
Rapid survey technique
Comprehensive survey technique
Source testing

FIGURE 3. EMISSION INVENTORY TECHNIQUES

The techniques are presented as a continuous line function to indicate that combinations of adjacent methods are appropriate. For example, an inventory based primarily on the rapid survey technique may also incorporate some of the features and requirements of a comprehensive survey. The major types of inventory techniques are described below.

A very gross appraisal of air pollutant emissions in an area may be derived almost entirely through the use of published data. Field visits, questionnaires, and stack testing are not utilized. For most urban areas published statistics are available on amounts and types of fuels burned, automobile registrations, and population; these statistics can be used as indicators of many pollution-generating activities. This method yields only a rough estimate of total annual emissions, without geographical or seasonal definition. Generally, the required calculations can be completed in one or two weeks, if statistical data are available.

The next major type of inventory is generally referred to as the Rapid Survey Technique. The rapid survey provides some definition of both geographical and seasonal variations in emission rates. The rapid survey incorporates available data but also introduces further refinements through selection of 50 to 100 major point sources for which specific information is obtained, usually by personal contact. The use of grid coordinate systems allows for geographic definition of emission rates. Whereas the point sources are located precisely, various approximating techniques are used to describe the locations and emissions from area sources over the city. In places where point sources account for the majority of emissions, this technique provides good appraisal. Experience has shown that on the average in a city of one-half to two million inhabitants, two persons working full time can complete a rapid survey in 6 to 8 weeks.

The third major type of inventory is labelled a comprehensive survey. In addition to providing more detail on area and temporal variation of emissions, the comprehensive survey provides additional information on point sources such as stack diameter, temperature, velocity, and height above ground level--data that are valuable in air quality modeling but do not necessarily increase the accuracy of overall emissions estimates.

Unlike the rapid survey, a comprehensive inventory requires extensive visits and mailing of questionnaires; it may also involve some stack testing. In some cities or regions, regulations require that information on the major sources of emissions must be supplied to the appropriate government agency. In these cases, a very accurate and complete inventory can be made.

In the case of motor vehicle emissions, the comprehensive inventory will require detailed information on vehicle mileage and speeds as well as emission factors that are based on the vehicle age and weight distribution and the driving mode of the particular area.

The major differences between a rapid and comprehensive survey are the number of major emitters (point sources) that are appraised individually and the amount and type of information that is required.

In addition, significant categories of area sources, e.g., road vehicles and domestic heating, are investigated more fully.

The comprehensive survey provides more accurate estimates of the geographic distribution of emissions, since more of the emissions are located on an individual basis. Completion of comprehensive survey would require at least one year of time and approximately two man-years of effort for a city of 500,000 to 2,000,000 inhabitants. There may be notable exceptions; regions containing many diverse industries will, of course, require much more effort.

Increased accuracy can be obtained if actual exhaust measurements are made, either through continuous monitoring of source emissions or through a source testing program. Continuous monitoring provides an accurate estimate of total emissions from an individual plant and also yields data on hour-to-hour and day-to-day variability of emissions. Because of the relatively high expenses, however, continuous monitoring usually is limited to a few large sources and perhaps, on a statistical basis, to some area source categories. A stack sampling program to support an emission inventory can provide reliable emission factors for an individual source and also can improve the accuracy of the emission factor formulated for the entire source category by providing valid data to be arranged with similar measurements.

In determining the type of survey to be conducted for an air pollution assessment activity, one must take into account the available resources (time, money, and manpower), the purposes for which the data will be used, and the characteristics of the area under study. The four major emissions survey techniques are summarized and compared in Table 1. An air pollution assessment study that incorporates modeling requires geographic definition of emissions. As a minimum, therefore, the rapid survey technique must be applied. Areas with a multitude of process industries require more comprehensive evaluation of sources than the rapid survey technique can provide. This is also true in areas in which 500 or even 1,000 larger sources may need to be investigated so that most of the emissions may be located precisely. Furthermore, where the air pollution assessment is to be made on a short-term basis, i.e., for prediction of hourly or 2-hour concentrations, data derived from rapid surveys are not sufficient.

IV. Survey Procedure

In conducting both the rapid survey and the comprehensive inventory the same general approach is followed. The survey procedure is divided into three major tasks:

TABLE I. Summary of Emission Inventory Techniques

	METHODS OF DATA COLLECTION USED				DEFINITION OF EMISSIONS						
					Geographic			Temporal			
Type	Published Data	Question-naire	Field Visits	Source Testing	Area Totals	Grid Zones	Number of Point Sources	Annual	Seasonal	Other	Resource Requirements Man-Months
Published Data	YES	NO	NO	NO	YES	NO	0	YES	NO	NO	½ - 1
Rapid Survey Techniques	YES	SOME	SOME	NO	YES	YES	50 - 100	YES	YES	NO	4
Comprehensive	YES	YES	YES	SOME	YES	YES	>200	YES	YES	DAILY or HOURLY	24

- Inventory design
- Collection of basic data
- Calculation of emissions

These tasks are briefly summarized in the following subsections.

A. Inventory design. This task entails the selection of (1) the boundaries of the study area, (2) the grid coordinate systems, (3) the pollutants to be assessed, and (4) the degree of geographic and temporal definition required.

A study area usually follows the boundaries of established political jurisdictions, such as a city or a planning district. Where practicable, the study area should be expanded to encompass areas of expected future growth, so that a baseline for future comparisons may be drawn. For purposes of modeling, it is desirable to include all of the sources that may affect the region's air quality so that the air masses moving into the region may be assumed to be of "background" quality.

A grid coordinate system is applied to subdivide the study area to identify locations of sources and emissions. For purposes of modeling, a regular system of square grids is highly desirable. The most commonly used systems are based on the Gauss-Krueger (similar to the Universal Transverse Mercator (UTM)) coordinate system. An important decision in development of a grid coordinate system is choice of grid size. Although geographic variability of emissions may be better defined with a smaller grid, the data requirements are substantially increased. In many situations the lack of sufficient data will preclude the use of an extremely fine grid.

A 1 x 1 km grid is commonly used for densely populated areas of the city, expanded to 5 x 5 km for the outlying areas.

Although an emissions inventory can be pollutant specific--e.g., a carbon monoxide inventory--emissions estimates generally are made jointly for at least the five major pollutants, viz., particulates, SO_x, CO, NO_x, and hydrocarbons. With minor exceptions, such as efficiencies of equipment for control of particulate emissions, the same basic information is required for estimating all of these pollutants.

Emission rates can be readily estimated on an annual or seasonal basis and reported as totals or in terms of an average day. This degree of definition suffices for use with long-term models, but not with short-term predictive models, which require additional information on daily and hourly variations in emissions.

B. Collection of basic data. "Basic data" refers to all information that is collected and used together with emission factors to estimate emission rates. Examples of "basic data" are fuel consumption rates, sulfur content of fuels, production rates of materials, vehicle travel, and the like. The availability of these data varies from one location to the next, requiring the use of different approaches in different situations. Experience has shown that a sufficient body of data exists for most urban areas to allow an adequate inventory. The basic approaches for estimating emissions are discussed individually by source category.

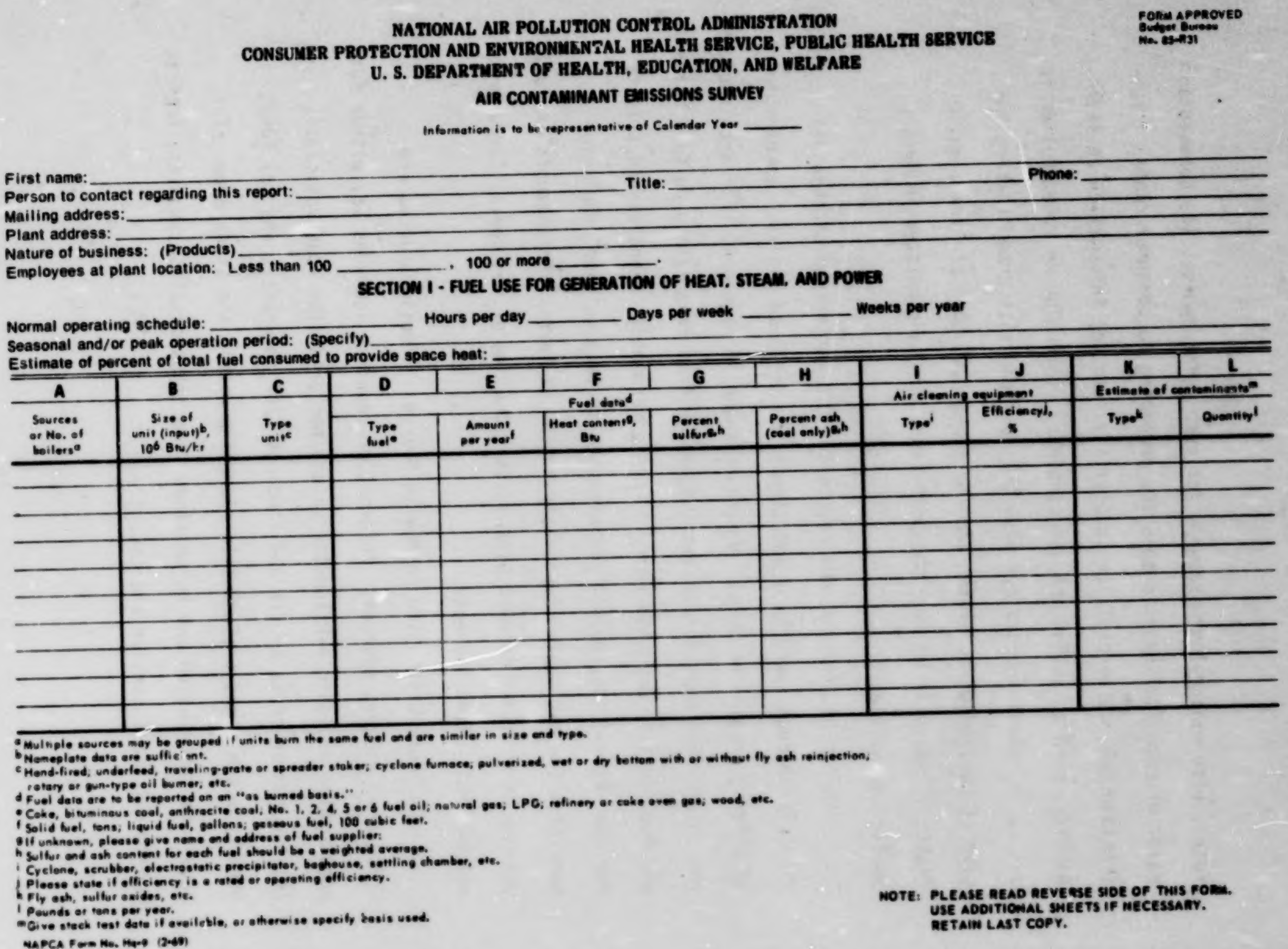
(1) Fuel Combustion in Stationary Sources. Estimation of emissions from this category requires information on (a) fuel consumption

rates, with seasonal breakdowns, for each point source, (b) consumption rates of each fuel by grid area and according to consumer class (residential, commercial, or industrial), and (c) information on fuel quality, such as sulfur and ash contents. (Although no rule applies in all cases, point sources are generally defined as sources that in the case of SO_2 and particulates emit more than 100 tons per year, while lesser values will be used for pollutants that are emitted in much smaller quantities.)

For point sources, the requisite information can be obtained directly through the use of questionnaires or field visits. An example of a fuel consumption questionnaire is shown in Figure 4. For area sources, the information must be derived indirectly from information on fuel sales and fuel quality obtained from various governmental agencies and private fuel marketers, coupled with information on land use and population densities for estimating fuel distribution patterns. Refinements in fuel use may be obtained through statistical sampling of residences, industries, and business establishments.

(2) Fuel Combustion in Mobile Sources. Mobile sources are considered as area sources. Information required includes (a) either fuel consumption or vehicle-kilometer values per grid (for road vehicles), (b) the number of take-offs and landings (for aircraft), and (c) fuels used by vessels and trains while operating within the study area. The requisite information can be obtained from transportation studies, traffic departments, and similar sources.

FIGURE 4. FUEL CONSUMPTION QUESTIONNAIRE



FORM APPROVED
Budget Bureau
No. 85-R31

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE, PUBLIC HEALTH SERVICE
U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

AIR CONTAMINANT EMISSIONS SURVEY

Information is to be representative of Calendar Year ________

First name: ____
Person to contact regarding this report: ________________ Title: ________________ Phone: ________
Mailing address: ____
Plant address: ____
Nature of business: (Products) ____
Employees at plant location: Less than 100 __________ , 100 or more __________ .

SECTION I - FUEL USE FOR GENERATION OF HEAT, STEAM, AND POWER

Normal operating schedule: ______________ Hours per day __________ Days per week __________ Weeks per year
Seasonal and/or peak operation period: (Specify) ____
Estimate of percent of total fuel consumed to provide space heat: ____

A	B	C	D	E	F	G	H	I	J	K	L
			Fuel data[d]					Air cleaning equipment		Estimate of contaminants[m]	
Sources or No. of boilers[a]	Size of unit (input)[b], 10^6 Btu/hr	Type unit[c]	Type fuel[e]	Amount per year[f]	Heat content[g], Btu	Percent sulfur[g,h]	Percent ash (coal only)[g,h]	Type[i]	Efficiency[j], %	Type[k]	Quantity[l]

[a] Multiple sources may be grouped if units burn the same fuel and are similar in size and type.
[b] Nameplate data are sufficient.
[c] Hand-fired; underfeed, traveling-grate or spreader stoker; cyclone furnace; pulverized, wet or dry bottom with or without fly ash reinjection; rotary or gun-type oil burner, etc.
[d] Fuel data are to be reported on an "as burned basis."
[e] Coke, bituminous coal, anthracite coal, No. 1, 2, 4, 5 or 6 fuel oil; natural gas; LPG; refinery or coke oven gas; wood, etc.
[f] Solid fuel, tons; liquid fuel, gallons; gaseous fuel, 100 cubic feet.
[g] If unknown, please give name and address of fuel supplier.
[h] Sulfur and ash content for each fuel should be a weighted average.
[i] Cyclone, scrubber, electrostatic precipitator, baghouse, settling chamber, etc.
[j] Please state if efficiency is a rated or operating efficiency.
[k] Fly ash, sulfur oxides, etc.
[l] Pounds or tons per year.
[m] Give stack test data if available, or otherwise specify basis used.

NAPCA Form No. Hq-9 (2-69)

NOTE: PLEASE READ REVERSE SIDE OF THIS FORM.
USE ADDITIONAL SHEETS IF NECESSARY.
RETAIN LAST COPY.

(3) Industrial Processes. All sources in this category must be considered individually as point sources. The requisite information is obtained through questionnaires or field visits. An example questionnaire is shown in Figure 5.

(4) Solid Waste Disposal. The data for this category are typically obtained by estimating the amount of combustible waste generated in the area, subtracting the amount collected and disposed of at central facilities such as incinerators and open burning dumps (point sources), and distributing the remainder of the inventory throughout the area in proportion to population in the case of domestic waste and according to industrial locations for industrial waste.

(5) Evaporation of Organic Substances. Both, point and area sources are included in this category. Typical point sources are refineries, storage tank farms, and petrochemical plants; the necessary information must be obtained on an individual basis. The emissions from area sources, such as dry cleaning establishments and gasoline service stations, are estimated using statistical data, e.g., amount of solvent used and the quantity of gasoline sold.

C. Calculation of Emissions. After the requisite basic data have been compiled, emissions are calculated using the previously mentioned emission factors.

Although emissions factors for almost all of the major source types have been compiled and are available in the literature, they cannot be applied indiscriminately. Differences in technologies, fuel types, and operating and maintenance conditions in different locations can result

FIGURE 5. PROCESS EMISSIONS QUESTIONNAIRE

NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE, PUBLIC HEALTH SERVICE
U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

AIR CONTAMINANT EMISSIONS SURVEY

SECTION II - PROCESS EMISSIONS

Normal operating schedule: ____________ Hours per day ____________ Days per week ____________ Weeks per year.
Seasonal and/or peak operation period: ____________
Note: For intermittent operations, indicate approximate frequency and duration so that estimates of yearly emissions may be obtained.

A	B	C	D	E	F	G	H
Processes or operations releasing contaminants to atmosphere[a,b]	Materials processed and/or used at operations		Quantity of gas discharged from process or operation	Type and efficiency air cleaning equipment[e,f]	Estimate of contaminants		Basis of estimate[h] (Please specify basis)
	Type[c]	Quantity per year[d]			Type[g]	Quantity per year[d]	

[a] Multiple sources may be grouped if units are similar in size and type.
[b] Sulfuric acid - chamber, aluminum smelting-crucible furnace, iron melting-cupola, cement manufacture - dry process, solvent cleaning, or other (please specify).
[c] Acid produced, tons; metal charged or processed, tons; cement produced, bbl.; solvent consumed, gallons; etc. per year. Specific quantities per year are not required if complete emission rate quantities are given in columns F and G.
[d] Pounds, tons, or gallons per year.
[e] Baghouse. electrostatic precipitator, cyclone, settling chamber, wet scrubber, etc.
[f] Please state if efficiency is a rated or operating efficiency.
[g] Dust, fume, gas, etc. emitted: iron oxide, mineral or rock dust, trichlorethylene, formaldehyde, sulfur dioxide, etc.
[h] Process material balance studies, field tests by plant or by equipment manufacturers, or other basis.

Any supplemental material or data considered pertinent (reports, summaries, test results, maps, flow diagrams) may be submitted with this form.

Date	Name and title of official submitting reports

NOTE: PLEASE READ REVERSE SIDE OF THIS FORM.
USE ADDITIONAL SHEETS IF NECESSARY.
RETAIN LAST COPY.

in drastically different emission rates. This is particularly true in surveys of industrial processes; the sources under study must be compared in depth with those from which emission factors were derived. Such surveys may require modification of the emissions factors through engineering calculations or even field testing of sources.

It is emphasized that emissions factors are statistical averages based on tests performed on a number of like or closely similar sources. Appliction of the factor to a single source can result in a large discrepancy between estimated and actual emissions rates. When large numbers of these sources are considered together, however, the discrepancies should be minimal.

Emission factors for road vehicles are not unlike those used for stationary sources. The emissions are still expressed in terms of the mass of pollutant as a function of usage index. Emission factors are derived through statistical testing of a sample of vehicles through a simulated on-the-road driving cycle. Because of basic differences in vehicle population, terrain and driving habits, several test cycles have been developed. Examples are the U. S. Federal Test Procedure and the ECE test cycle. The selection of the appropriate cycle is a very important step.

It is extremely important that the basic data collected are carefully checked and reviewed for validity. This may be done by several ways. The data derived through questionnaires or personal visits should be checked carefully to detect large errors. The validity of total emission estimates may be checked by calculations made on the basis of different techniques. For example, an estimate of the region-wide emissions of SO_2 may be derived from total fuel consumption data on one hand and by adding the quantities derived for individual point sources and source consumer categories. Such cross-checking is encouraged wherever possible to avoid large errors.

REFERENCES

1. "Compilation of Air Pollutant Emission Factors", (revised) Publication No. AP-42, Environmental Protection Agency, Research Triangle Park, North Carolina, February 1972.

2. "Rapid Survey Technique for Estimating Community Air Pollution Emissions", Ozolina, G., Smith, R., Public Health Service, Publication No. AP-29, U. S. Department of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio, October 1966.

3. "Recent Investigations of the Emissions of Automobiles in the Cologne Metropolitan Area", May, H., F. J. Dreyhaupt, E. Plassman and W. Muller, Zeitsch Staub. 2:19

4. "Atmospheric Pollution from Petrol Engines, Baseline Exhaust Emissions of Vehicles Tested to the Draft European Procedure", The Motor Industry Research Associaiton, Warwickshire, England, February 1968.

AIR QUALITY MONITORING

I. Role of Monitoring in Assessments

Monitoring helps to demonstrate the need for control (by defining pollution levels), then guides the development of control strategies (by showing the degree of control needed), and finally indicates how effective the controls are (by allowing comparisons with established standards and/or by comparisons of "before and after" values).

Assessment of an area's air pollution problem requires information on the ambient air levels and their spatial and temporal variability. Such data are needed in the development of working air quality models by providing a comparison between model-predicted concentrations and observed values. Where necessary, the model then can be calibrated by the established ratios of the predicted and the observed concentrations.

This section of the report provides guidelines for the design and operation of air pollution monitoring networks required in assessment studies. It discusses the selection of (1) appropriate monitoring systems, (2) instruments and methods, (3) the number and location of sampling sites, (4) sampling duration, (5) sampling frequencies, and (6) data handling systems. It is important to note that the choices are strongly influenced by local conditions and also by the available resources.

II. Monitoring Systems

Ambient air quality data may be obtained through the use of a variety of techniques and schemes: (1) the operation of mobile or fixed sampling networks, and (2) the use of continuous monitors or integrated samplers. Decisions regarding these monitoring techniques constitute the first important steps in design of a monitoring network.

A. Fixed versus Mobile Sampling. Fixed point sampling entails a network of monitoring stations at selected sites, operated simultaneously throughout the study. Stations are permanent, or at least long-term, installations. In a mobile sampling network the monitoring/sampling instruments are rotated on schedule among selected locations. The monitoring/sampling is not conducted simultaneously at all locations, and the equipment is generally housed in trailers, automobiles, or other mobile units. An advantage of fixed sampling is that measurements are made concurrently at all sites, providing directly comparable information, which is particularly important in determining relationship of polluting sources to local air quality and in tracing dispersion of pollutants throughout the area. The chief advantages of mobile sampling is that air quality measurements can be made at many sites--far more than would be feasible in a fixed sampling program. Mobile sampling provides much better definition of the geographical variations if the program is long enough to generate meaningful data.

B. Continuous Versus Integrated Sampling. Continuous monitoring is conducted with devices that operate as both sampler and analyzer. Pollutant concentrations are instantaneously displayed on a dial, continuously recorded on a chart, or, in telemetry systems, transmitted to a control center. Integrated sampling is done with devices that collect a sample over some speicified time interval after which the sample is sent to a laboratory for analysis. The result is a single pollutant concentration that has been integrated, or averaged, over the entire sampling period.

Continuous or automatic monitoring instruments offer some advantages over integrating samplers: capability for furnishing short interval data, rapid availability of data, output of instrument can be telemetered to a central point and lesser requirements for laboratory support. They also may be necessary to monitor some pollutants where no integrating method is available or where it is necessary to collect data over short averaging times, for example 15 minutes. Automated monitors also have some drawbacks. They require extensive maintenance, calibration, and the operators have to be more technically trained. Many of these pollutants can be measured by either method.

The selection of a monitoring system is influenced by the averaging time for which concentrations are desired, i.e., 15-minute, 1-hour, 8-hour, 12-hour, or 24-hour time intervals. It should be consistent with the averaging times specified by air quality criteria. For example, in assessing SO_2 levels, good coverage can be provided by use of integrated samplers widely dispersed over the area and one or more continuous sampler/analyzers situated in heavily populated areas. The integrated samplers define SO_2 levels over a broad area, and the continuous devices provide detailed information on diurnal patterns. The short averaging time of interest for CO and oxidants (ozone) dictates the use of continuous monitors for these pollutants.

III. Selection of Instrumentation and Methods

Choice of instrumentation for an air monitoring network depends on the following factors:

- Type of pollutants
- Averaging time specified by air quality criteria or standards

- Expected pollutant levels
- Available resources
- Availability of trained personnel
- Presence in the air of interferring materials
- Time requirements for data

Most pollutants may be monitored by a number of different methods and techniques. The selection of the methodology to be used is an important step in the design of the monitoring portion of the assessment study.

A. Sulfur Dioxide. As shown in Table 2, numerous techniques and instruments are available for monitoring SO_2. The SO_2 impinger method is the simplest of the available techniques; in conjunction with an analytical laboratory, it permits integrated monitoring at a large number of sampling points at a relatively low cost. High specificity for SO_2 can be achieved with the impinger method by use of the West-Gaeke analysis; all known interferences are eliminated by addition of appropriate reagents (for example, heavy metals can be removed with a chelating agent). Of the continuous monitoring techniques available for SO_2, the colorimetric West-Gaeke method again offers a specific analysis. Coulometric analysis also has good specificity and the added advantage of proven reliability in the field. Conductometric methods are also reliable in the field but suffer loss of specificity from interferences such as other acid gases. In atmospheres where concentrations of other sulfur compounds are small, the flame photometric total sulfur analyzer may be used. This instrument offers very high sensitivity (3.0 ug/m^3) but has not been thoroughly proven in the field.

TABLE 2

METHODS FOR MEASURING SULFUR DIOXIDE

Method	Classification	Specificity	Sensitivity	Comments	Approximate Cost*
Impinger	Integrated analysis, 24 - hour sampling period	High specificity with colorimetric West-Gaeke analysis. Low specificity with peroxide titrimetric analysis.	0.01 ppm.	Both West-Gaeke and peroxide method require laboratory analytical capability	Sampler – \$200 Lab. Equip. – \$3,000
Colorimetric auto-anaylzer	Continuous	High specificity with West - Gaeke method	0.005 ppm.	Requires trained operator support, frequent maintenance	\$3,000 without recorder
Coulometric	Continuous	Good specificity	0.005 ppm.	Reliable operation; easy maintenance in the field	\$2,500 without recorder
Conductometric	Continuous	Fair specificity; other acid gases interfere	0.01 ppm.	Reliable operation	\$2,000 without recorder
Flame Photometric	Continuous	Specific for total sulfur; can measure SO_2 when no other sulfur - containing gases are present	0.001 ppm.	Field reliability not proven	\$5,000 without recorder
Silica Gel	Integrated analysis, 10 to 30 min.	High specificity for SO_2 with prefilter	0.01 ppm.	Requires laboratory support	\$ 600

*Does not include equipment and setup costs for calibrating instruments – normally \$500 – \$1,000.

For an initial SO_2 assessment project, integrated impinger samplers with West-Gaeke analysis and continuous monitors based on the West-Gaeke or equivalent methods are recommended.

B. Total Suspended Particulates. Table 3 summarizes the available methods for measuring concentrations of suspended particulate matter. The most specific and one of the least expensive is the Hi-Vol technique for measuring TSP, an integrated method on a glass fiber filter. One type of tape sampler and th smokeshade device estimate particulate levels indirectly through optical absorbance or reflectance measurements of the dark-colored particles that have stained a paper filter. Another type of tape sampler, employing the absorption of beta radiation, provides a means for continuous measurement of particulate loadings in the atmosphere. Continuous particle-counting or visibility measuring devices, including the integrating nephelometer, offer the advantage of rapid data readout but do not provide a direct measure of atmospheric particulate loading. The Hi-Vol method or equivalent is preferred for measuring total suspended particulate matter.

In addition to performing gravimetric analysis on the Hi-Vol glass fiber filters, the analyst can make chemical determinations on the collected particulate matter. Ordinarily the filters are cut into 1-inch strips, ashed in a low temperature ashing device to remove the carbonaceous material, and extracted with appropriate solvents.

For trace metal analysis, a filter section is extracted with acids, usually nitric and hydrochloric acids, and analyzed with an emission spectrographic, atomic absorption spectrophotometer, or wet chemical

TABLE 3

METHODS FOR MEASURING SUSPENDED PARTICULATES

Method	Classification	Specificity	Sensitivity	Comments	Approx. Cost
Hi-Vol	Integrated, 24-hour sampling	Highly specific, gravimetric analysis	Approximately 2 ug/m^3	Requires lab support; humidity/temp. controlled weighing facility	$ 200
Membrane filter sampler	Integrated, 24-hour sampling	Highly specific, gravimetric analy-	Approximately 2 ug/m3	Allows analysis for asbestos, barium, boron, etc.	600
Tape sampler–1	Continuous-integrated samples collected on hour or two-hour basis.	Fair; depends on physical properties of the particles (size, shape, color)	Not Known	Optical transmittance or reflectance measured is related to soiling properties of particles	800
Smoke-shade	Integrated 24-hour sampling	Fair; depends mostly on color of particles; light colored particles; not measured	Approximately 5 ug/m^3	Reflectance measurement; only dark staining particles give a reading	100
Cascade Impactor	Integrated 24-hour sampling	Highly specific, gravimetric analysis	Approximately 10 ug/m^3	Provides particle size information as well as mass loading	400-1,500
Particle Nephelometer	Continuous	Fair; measurement affected by high humidity	All particles above 0.2 u diameter measured	Not widely used at present; requires further field testing	3,500
Tape sampler–2	Continuous-integrated samples collected on 30 minutes or more	Highly specific	Approximately 20 ug/m for 30	Absorption of Beta radiation	3,500

procedures. Most of the heavy metals of interest as air pollutants can be analyzed by this procedure; these metals include lead, cadmium, zinc, copper, iron, nickel, vanadium, and manganese. Other collection and analytical methods must be used to determine mercury and selenium (usually neutron activation analysis).

The filter sections can be extracted by water to obtain the more common aqueous soluble non-metals such as sulfates, nitrates, chlorides, ammonium, and water soluble fluorides. The analytical procedures are usually based on wet chemical spectrophotometric analysis, although the ion specific electrodes for chloride and for fluoride determinations are also used.

Organic components may be determined on larger, unashed portions of the filters. Ordinarily a benzene extraction is made using a Soxhlet extractor followed by thin layer chromotography. Analysis of total benzene-soluble material and selected polynuclear hydrocarbons such as benzo-a-pyrene is made. Chromatographic analysis may also be carried out to identify in more detail selected hydrocarbons.

C. Carbon Monoxide. Integrated sampling of carbon monoxide has been practiced in the past for measuring occupational exposures. Current emphasis is centered on obtaining continuous data on ambient air concentrations. There are several reasons for this. The air quality criteria shows the need for short-term data, i.e., 1-hour and 8-hour averages. Also, carbon monoxide is not very reactive or soluble resulting in difficulties in sample preservation prior to laboratory analysis.

The most commonly used instruments for carbon monoxide monitoring in the atmosphere are non-dispersive infrared (NDIR) analyzers. These devices have been in use for a number of years and have proved to be reliable and specific. An NDIR analyzer operates on the principle that CO has a sufficiently characteristic infrared absorption spectrum and that the absorption of infrared radiation by the CO molecule can be used as a measure of CO concentration in the presence of other gases. Measuring ranges usually extend from 1 to 50 ppm or from 1 to 100 ppm of CO. Carbon dioxide and water vapor interfere in the determination of the CO; these interferences, however, can selectively be removed. Numerous manufacturers produce CO instruments at costs ranging from $2500 to $5000.

Other methods for monitoring CO include mercury vapor analyzers, gas chromatographs, and instruments based on galvanic and coulometric principles.

D. Hydrocarbons. With a few exceptions, atmospheric hydrocarbon measurements are made with continuous, relatively complex instruments. The most common measurements are of total hydrocarbons and more recently of the non-methane hydrocarbons. The value of total hydrocarbon data is limited since the high background level of naturally occuring methane obscures the variation in levels of the reactive hydrocarbon species (those involved in photochemical reactions.)

Total hydrocarbons have traditionally been measured with a flame ionization detector. These analyzers are sensitive, reliable, and suitable for the measurement of most hydrocarbons. This detector is based on the principal that a pure hydrogen flame contains an almost negligible number of ions while the addition of even traces of organic compounds produces a large number of ions. The measured current is proportion to the hydrocarbon concentration of the sample. There are several models available within a price range of $2,000 to $5,000.

The recently developed gas chromatographic techniques can simultaneously measure methane, total hydrocarbons, and carbon monoxide. This instrument separates carbon monoxide and methane by chromatographic techniques and measures hydrocarbons by a flame ionization detector.

Also gas chromatography has been used to measure C_1 - C_5 hydrocarbons. This procedure yields valuable information on specific hydrocarbons found in the environment. The operation of these instruments require considerable experience and maintenance, but provide more valuable information concerning those hydrocarbons that enter into the formation of photochemical smog. The cost range of these instruments are $4,000 - $7,000.

E. Oxidants. Total oxidants may be measured by use of integrated samplers followed by laboratory analysis or by automatic sampler-analyzers. Both methods are based on the reaction of oxidizing substances with potassium iodide. Normally the integrated samples are limited to a sampling duration of 30 minutes or less and require analysis within one hour to provide reliable data. The problem of reagent instability is minimized through the use of the automatic analyzers where the sample is analyzed continously. It should be realized that for both cases, positive interferences may result from other oxidizing substances such as peracetyl nitrates and nitrogen dioxide. The cost of bubblers is about $200 and that of continous analyzers is in the range of $3000 to $7000.

An instrument specifically for the measurement of ozone has recently become available. Ozone is by far the predominant oxidant in most atmospheres (more than 99%); therefore, this instrument provides reliable oxidant measurement. The operation is based on the measurement of light emitted by the chemiluminescent reaction of the atmospheric ozone with ethylene in the reaction cell. The resultant light emitted is measured photometrically and is proportional to the amount of ozone present in the sample. The method does not suffer from any known interferences and has been adequately evaluated for field use. It has been specified as the reference method in the U. S. The approximate cost is between $40000 and $5000.

F. Nitrogen Dioxide. Both, integrated and continuous monitoring methods have been used extensively to measure ambient nitrogen dioxide. Most of the integrated sampling is performed on a 24-hour basis, e.g., a sample is collected in a solution over the entire time period and then taken to a laboratory for analysis. The two most common techniques are the Jacobs-Hochheiser and the Griess-Saltzman methods. In the case of the latter, the sample is collected directly into the reagent whereas for the Jacobs-Hochheiser test the sample is collected into an alkaline solution. Both methods depend on a diazotizing coupling procedure to form an intensely colored dye. Both techniques have certain limitations. The instability of the dye formed limits the use of the Griess-Saltzman technique to short-term sampling (3o minutes) and requires immediate analysis. It has been recently found that the collection efficiency in the Jacobs-

Hochheiser technique varies depending upon the ambient concentration of NO_2. In the range of 95-160 ug/m^3, the collection efficiency is 35 ± 5%. As the concentration approaches 30 ug/m^3, the collection efficiency is approximately 70% and at 300 ug/m^3, it drops off to less than 20%. The U. S. Environmental Protection Agency is extensively investigating this problem and will soon issue a replacement method. Also, there is an attempt to develop a conversion scale to relate results from the Jacobs-Hochheiser method to real ambient concentrations.

One continuous instrument for measuring NO_2 employs the Griess-Saltzman reagent. This instrument collects the NO_2 directly into the reagent and the resulting color measured in the instrument. One of the newer and perhaps the most promising continuous monitor for NO_2 uses the chemiluminescent principle. This method is now in the final stage of field testing. Another method, employing electrochemistry, is currently under consideration. The cost of bubblers is again approximately $200 and that of the ocntinuous instruments is in the range of $3500 to $5000.

G. Laboratory Requirements. An analytical laboratory is required for chemical analysis of SO_2, NO_2, and oxidant samples, gravimetric analysis of Hi-Vol filter samples, preparation of reagents, and examination and calibration of sampling instruments. Minimum laboratory equipment needed for an assessment study includes:

- Analytical balance
- Spectrophotometer or colorimeter
- Water distillation apparatus
- Permeation tube apparatus for dynamic calibration

- Gas measuring meters
- Supporting laboratory glassware
- Reagents

For weighing Hi-Vol filters, an area having controlled humidity and temperature is required to condition the filters (usually relative humidity less than 50% and temperature of 18.3°-23.9°C). Minimum cost of an assessment laboratory facility is approximately $3000, exclusive of temperature-humidity control devices. The cost can increase appreciably if additional chemical analyses are to be made on the Hi-Vol filters.

IV. Number and Location of Sampling Sites

Only approximate guidelines can be given for estimating the number of stations needed for assessing the air quality in a given area. The determining factors usually include the types of data needed, population and size of the area, spatial distribution of industry, resources available, and topographical and meteorological factors. A rough indication of the minimum number of sampling stations required for a given area can be obtained from Figure 6. The specific locations of sampling stations should be selected with a view toward delineating geographical pollution variability throughout the area. Population density maps, past air quality data, and emission source information are useful in this task. In general, the aim should be to place the majority of stations in the more heavily polluted areas and also in areas of highest population densities. Adequate coverage of the entire study area is imperative; no large area should be left without some form of measuring devices.

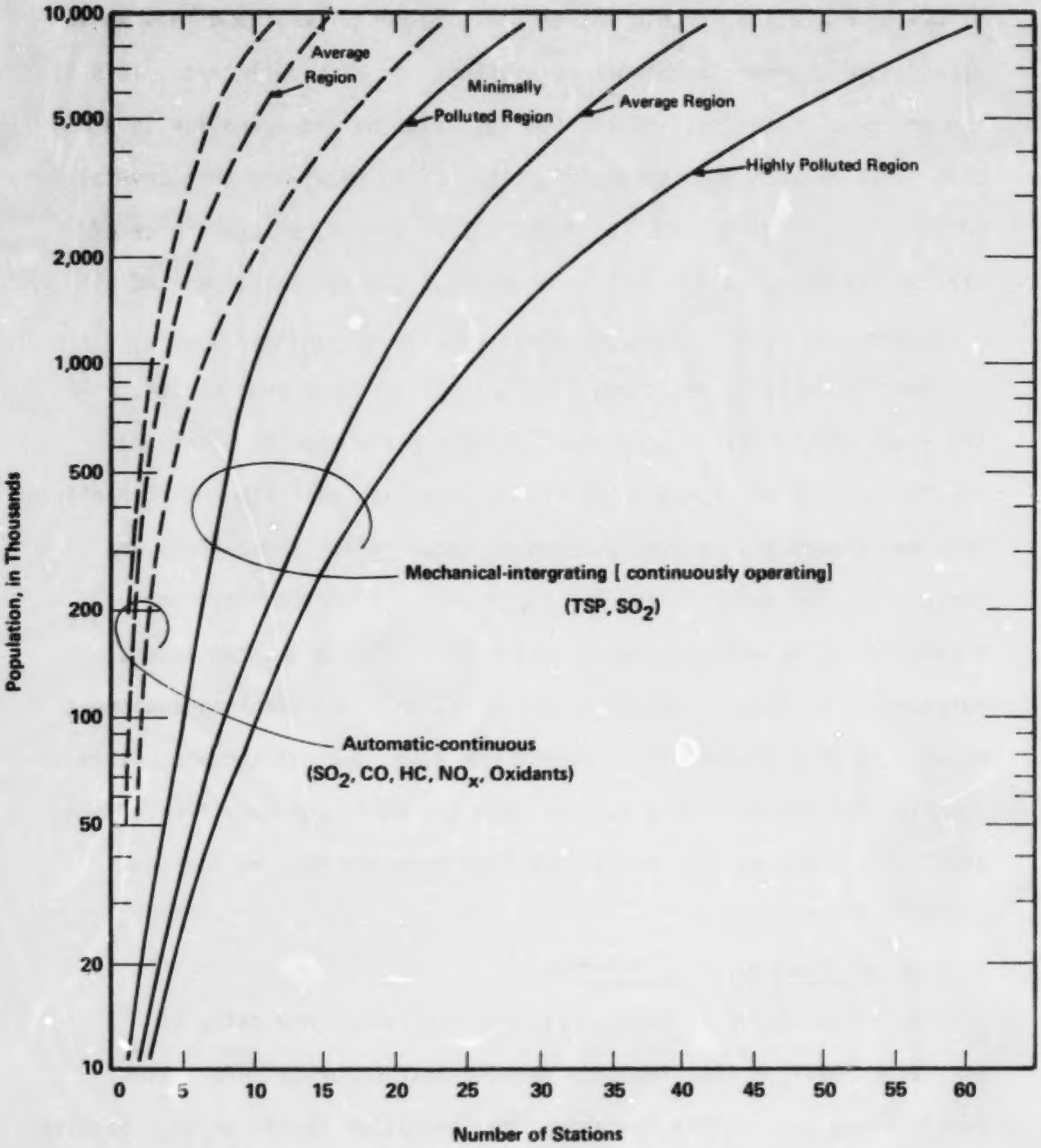


FIGURE 6. RELATIONSHIP BETWEEN MINIMUM NUMBER OF STATIONS AND REGION POPULATION

Ideally, the placement of samplers/monitors for a particular pollutant should be based on the geographical patterns of that pollutant, i.e., CO monitors should be located to yield a representative sampling of CO concentrations within the region. In most likelihood this would necessitate a separate network of stations for each pollutant. This is not practical. The cost of station installation and operation is high thus limiting the total number of stations and requiring that several pollutants are monitored at a common site. Therefore, the choice of station locations is critical in order that the concentrations of all pollutants measured be closely representative of regional levels.

When approximate locations for the stations have been chosen, the exact sites must be selected. Hi-Vols are generally placed on rooftops of one or two-story buildings to avoid reentrainment of particles from the ground and to provide greater security for instruments and personnel. The intermittent and continuous gas monitors are housed inside a shelter with a sampling probe projecting about two meters outside and at least 3 meters from the ground. All sampling equipment must be readily accessible to permit operation and maintenance; it is usually good practice to place the sampling equipment away from office and living areas so that noise emanating from the devices does not constitute a nuisance.

V. Sampling Frequency and Duration

The frequency of collecting samples can range from daily to biweekly. Daily collection provides the most accurate information, requiring no assumptions concerning concentration levels on days samples were not collected. Available resources can be the ultimate limiting factor on choice of sampling frequency.

Table 4 gives some idea of the sampling precision for total suspended particulates that can be expected for various sampling frequencies. Although Table 4 was developed from data obtained only in one city, Philadelphia, calculations have been made for other cities with similar results. The percent deviation of annual average from the true mean is shown for sampling frequencies ranging from daily to biweekly. Precision is poorer with decreasing sampling frequency. Every seventh day sampling leads to considerable error because of repetition of weekly patterns.

In an initial assessment study, it is desirable that daily 24-hour samples be collected; the minimum sampling frequency should not be less than once every sixth day. Sampling duration should cover portions of the heating and non-heating seasons for assessing air quality levels; therefore, at least six months of monitoring is required for an assessment project. Longer sampling periods are required for assessing trends and gauging the effectiveness of control measures.

In Table 5 a somewhat different approach was taken. On the basis of five years of monitoring data from an SO_2 station in Dusseldorf, Germany, the arithmetic mean value of this period and the standard deviation of single values for 1 hour and 24 hour averaging time was calculated. From this information the coefficient of variability for the arithmetic mean values of a statistical sample with different sample frequencies could be evaluated. The results are shown in columns 2 and

TABLE 4. RELATIONSHIP OF SAMPLING FREQUENCY TO THE PERCENT DEVIATION FROM THE TRUE MEAN[a]

Sample Taken Every Kth Day	Percent Deviation from the Annual Mean
K = 2	1.4
3	1.7
4	2.2
5	2.7
6	3.2
7	8.7
8	3.8
9	5.0
10	5.4
11	4.7
12	5.0
13	6.4

---

[a] based on evaluation of nine years of data for Philadelphia, Penn.

TABLE 5

RELATIONSHIP OF SAMPLING FREQUENCY TO THE COEFFICIENT OF VARIABILITY OF SAMPLE MEAN VALUES.

Sample Size (= samples per year)	Coefficient of Variability for Sample Mean Values (% of true mean)	
	1 HR.	24 HRS.
182	6.6	5.3
169	6.9	5.5
156	7.1	5.7
143	7.4	6.0
130	7.8	6.3
117	8.3	6.6
104	8.7	7.0
91	9.4	7.6
78	10.1	8.2
65	11.0	8.9
52	12.4	10.0
39	14.4	11.6
26	17.5	14.1

3 of Table 5. The sampling frequency in column 1 of Table 5 is comparable with column 1 of Table 4 in that in Table 5 on the average every Kth. day a sample is taken. For example, K=2 is equivalent to 182 (365 days per year/2) 1 hour or 24 hour values randomly distributed over the year. The coefficient of variability describes the range in which a deviation between the true annual mean and the sample mean value can be expected to fall, with a probability of approximately 70%. That is, with K=2, for 1 hour samples, there is a 70% probability that the sample mean value will fall within 6.6% of the true annual mean. On the other hand, a sample size necessary for a specific sample accuracy can be assessed by taking the corresponding figures of column 1 in Table 5.

VI. Design of a Data Processing System

In selection of a data processing system for an assessment study, the following questions must be answered:

- What resources are available for data processing?
- What quantity of air quality data is expected?
- What use will be made of the data?
- How rapidly will the data be needed?

Data handling systems for air monitoring can range from simple, hand-tabulated operations to sophisticated automatic acquisition devices, which operate in conjunction with telemetered computer-processed outputs. The objectives of the air monitoring program and the resources available dictate the type of data acquisition and analysis system required for the flow of air quality information.

In an initial air quality assessment study, laboratory results derived from the intermittent sampling network are usually tabulated manually. The tabulations should be made in standardized format that can be used for either manual or computer processing. A computer, if available, provides an efficient means for reducing the data to statistically meaningful forms, which can be readily interpreted and used in support of the modeling effort. Data from continuous monitoring, recorded graphically on strip charts, can be manually reduced to hourly averages; later computer processing can provide averages for different averaging times. Data reduction should be performed concurrently with network operation, with a minimum of lag time.

For a short-term assessment study, one year or less, the data handling system should be simple; that is, a procedure that combines hand tabulation and processing with computer backup for data analysis. For continuous monitoring equipment with data records on strip charts, data reduction by hand or by mechanical integrator is recommended.

VII. Operation of an Air Monitoring Network

The successful operation of a monitoring network requires a number of support activities. These tasks are many times overlooked during the planning phase resulting in delays in network implementation, unnecessary downtime of instruments, and data of questionable validity. The most important of these support activities are:

- Initial check and calibration of monitoring instruments
- Routine calibration activity
- Supplies and Maintenance
- Quality control

- Training

Before deployment at the sampling stations, all sampling/monitoring instruments must be checked for operational reliability and calibrated. A laboratory facility should be established to permit testing of each monitor for proper air and reagent flow rates for possible leaks in the various reagent flow systems, for normal electronic operation, and for proper functioning of all mechanical systems. The need for careful preevaluation cannot be over emphasized. Many operational problems may be uncovered and corrected through this type of an evaluation.

After each monitoring instrument has been judged operational, calibration checks must be routinely scheduled and performed to insure the continuous production of valid data. The use of both static and dynamic calibrations is recommended. Static calibration is used to check the response of the sensor. This involves the use of standardized solutions containing a known amount of the pollutant or filters which influence the response of the detector to some predetermined value.

The use of dynamic calibration cannot be over emphasized. Continuous automated measurements yield accurate data only if the measuring instruments have been calibrated with a known quality of gaseous pollutant while the complete system is operational in the field. To calibrate any instrument, the operator must use a method that delivers a known quantity to the system. For total hydrocarbons and carbon monoxide monitors, acceptable standard gases with certified analysis are obtainable from commercial sources. For sulfur dioxide and nitrogen dioxide monitors, gravimetrically calibrated permeation tubes can be utilized. A permeation tube may consist of a sealed FEP (fluorinated ethylene propylene) tube containing the liquefied gas kept at a constant temperature. Preparation, calibration, and use of these tubes are described in the literature. For calibrating oxidant and ozone analyzers, an ozone source is used.

No comparable calibration methods exist for hi-vol samplers. Careful calibration of the air flow metering devices on the sampler is the only standardization required. It has been demonstrated that the precision of duplicate hi-vol samplers sampling ambient aerosols currently is ±5% with a 95% confidence limit.

Before any monitor is selected for routine field use, it is extremely important to investigate the availability of replacement parts and required accessories. Many monitoring networks fail as a result of not using well-established, reliable, and convenient commercial sources. Also, calibration and carrier gases of known purity must be available on a continuing basis. Proper storage must be provided for unstable and toxic materials.

The proper use of quality control techniques will assure the validity of all monitoring data. The dynamic calibration previously described are a vital part of quality control. Additionally, careful attention must be paid in selecting only those procedures which have been properly standardized and/or recognized by an expert group within a given user population. Further, limits of acceptability must be determined according to the end uses of the data and calibration standards must then be routinely used to verify the performance of the procedure and the analyst. The proper use of quality control charts is described in the literature.

Operators may be trained either before or after the monitoring equipment is installed at the stations. Each operator should be instructed in field operation of the monitoring equipment before data are accepted for the study. Specific training should include:

- Monitoring equipment theory
- Recording of the instrument operational parameters--flow rate, zero and calibration checks, reagent indicator levels
- Routine maintenance
- Sample-handling procedures
- Simple field repairs

Each operator must thoroughly understand handling of the collected intermittent samples. Ordinarily, Hi-Vol particulate samples can be stored at room temperature indefinitely and returned to the laboratory for analysis at a later date. Bubbler solutions, however, should be analyzed as soon as possible after the sample is collected.

VIII. Reduction and Interpretation of Data

The purpose of an air quality monitoring program is to produce usable data. Data must be summarized in a convenient format and must be available when required. Values should be expressed in uniform units (metric system) and reduced to useful and systematic averaging periods.

A very important part of the entire monitoring effort is the validation of data. Whatever quality control procedures are used and the care that is exercised during the sampling and analysis phase, erroneous or questionable values can still be generated. It is for this reason that all data must be subjected to careful scrutiny prior to further treatment or publication to enable discarding erroneous data. Data validation may be performed either manually or by computer procedures.

The ideal data reduction system is flexible and is responsive to diverse needs--comparison with standards, calculation of dosages, and the like. The system should be capable of producing data averaged over 1 hour, 8 hours, 12 hours, 24 hours, 1 month, and 1 year. It should make readily available the maximum concentrations for each of these averaging times.

A system for coding, storing and retrieving data, called SAROAD (Storage and Retrieval of Aerometric Data) has been developed in the U. S. by the Environmental Protection Agency. Air quality data are recorded on computer-compatible data sheets, with standardized codes for station locations, type of data, type of sampler, sampling interval, and other factors. This system can very easily be applied to an assessment project and is recommended for such use.

The information collected in a monitoring effort should be presented in timely reports. In an air monitoring program, facilities and staff should be adequate to prepare and publish routine summaries of all data, to compile area-wide statistics, and to perform interpretive analysis of the impact of the data. Data summaries and interpretative reports should be distributed widely; they provide information for developing, validating, and refining diffusion models, and form the basis for control legislation.

REFERENCES

1. Federal Register, Volume 36, Number 84, Friday, April 30, 1971, pp. 8186-8201.

2. "Guidelines: Air Quality Surveillance Networks," EPA, Office of Air Programs, Research Triangle Park, N. C., May 1971, OAP Publication, AP-98.

3. O'Keeffe, A. E., and Ortman, G. C., "Primary Standards for Trace Gas Analysis," Anal. Chem., 38, 760 (1966).

4. Pate, J. B., and Tabor, E. C., "Analytical Aspects of the Use of Glass-Fiber Filters for the Collection and Analysis of Atmosphere Particulate Matter," Am. Ind. Hyg. Assoc. J. 23, 144-150 (1962).

5. Robson, C. D., and Foster, K. E., "Evaluation of Air Particulate Sampling Equipment," Am. Ind. Hyg. Assoc. J. 24, 404 (1962).

6. Scaringelli, F. P., Frey, S. A., and Saltzman, B. E., "Evaluation of Teflon Permeation Tubes for Use with Sulfur Dioxide," Am. Ind. Hyg. Assoc. J. 28, 260 (1967).

7. Scaringelli, F. P., O'Keeffe, A. E., Rosenberg, E., and Bell, J. P., "Preparation of Known Concentrations of Gases and Vapors with Permeation Devices Calibrated Gravimetrically," Anal. Chem. 42, 871 (1970).

8. Scaringelli, F. P., Saltzman, B. E., and Frey, S. A., "Spectrophotometric Determination of Atmospheric Sulfur Dioxide," Anal. Chem. 39, 1709 (1967).

9. Tierney, G. P., and Conner, W. D., "Hygroscopic Effects on Weight Determinations of Particulates Collected on Glass-Fiber Filters," Am. Ind. Hyg. Assoc. J. 28, 363 (1967).

10. West, P. W., and Gaeke, G. C., "Fixation of Sulfur Dioxide as Sulfitomercurate III and Subsequent Colorimetric Determination," Anal. Chem. 28, 1816 (1956).

11. "Selected Methods for the Measurement of Air Pollutants," U. S. Department of Health, Education, and Welfare, PHS Publication No. 999 - AP-11, 1965.

12. Lee, Jr., R. E., Caldwell, J. S., and Morgan, G. B., "The Evaluation of Methods for Measuring Suspended Particulate in Air," EPA Report in preparation.

13. Aurand, K., and Bosch, J., "Apparatus for the Continuous Determination of the Concentration of Dustlike Air Contaminations," Staub 27, 445-447 (1967).

14. Fuhrmann, H., "Recorded Measurement of Gaseous Immision Concentrations by Means of a New Analysis Apparatus," Staub 25, 266-270 (1965).

15. Preining, O., "The Goetzche Aerosol Spectrometer - Operation and Evaluation Problems," Stabu 22, 129-133 (1962).

16. Stratmann, H., and Buck, M., "Comparative Measurements for the Ascertainment of Sulfur Dioxide in the Atmosphere by Means of the Silica Gel Method and the TCM Method," Int. J. Air Water Pollution, 199-218 (1965).

17. "VDI Manual, Air Pollution Control, Preservation of Air Cleanness," Beuth-Vertrieb, GmbH, Berlin and Cologne.

18. "VDI Manual No. 2119, Measurements of Dust Deposits - Description and Instructions for Using the Apparatus," (1966).

19. "VDI Manual No. 2451, Measurements of Gaseous Emissions - Measurement of Sulfur Dioxide Concentrations," (1963)(1968).

20. Prinz, B., and Stratmann, H., "Conclusions from Continuous Measurements of Concentrations of Gaseous Air Contaminations Upon Statistics of Spreading Out Conditions," Staub, 1966, No. 12, p. 514.

21. Georgii, H. W., and Hoffman, L., "Estimation of SO_2 Concentrations Dependent Upon Meteorological Influence Factors," Staub, Vol. 26, 1966, No. 12.

22. Weber, E., "Contribution to the Residence Time of Sulfur Dioxide in a Polluted Atmosphere," Journ. Geoph. Res., 75, No. 13 (1970).

23. Breuer, W., and Winkler, K., "Sulfur Dioxide Immissions at Scanty Weather Condition Changes,: Staub 25, 98-101 (1965).

24. Breuer, W., "New Methods for Continuous Trace Analysis," Arch. Techn. Messen 396, 7-12 (1969).

25. Lahmann, E., "Investigation and Evaluation of the Atmosphere," Manual of the Food Chemistry, Vol. VIII, Part 1 and 2, Springer Verlag, Berlin-Heidelberg-New York, 1970.

26. "Users Manual: SAROAD (Storage and Retrieval of Aerometric Data)," Office of Air Programs, Publication No. APTD-0663, Environmental Protection Agency, Research Triangle Park, North Carolina, July 1971.

27. "SAROAD Parametric Coding Manual," Fair, D., Clements, J., Morgan, G., Office of Air Programs, Publication No. APTD-0633, Environmental Protection Agency, Research Triangle Park, North Carolina, July 1971.

28. Morgan, G. B. and Ozolins, G., "Air Quality Surveillance, Introduction to the Scientific Study of Atmospheric Pollution," D. Reidel Publishing Company, Dordrecht, Holland, 1971.

29. Hochheiser, S., Burmann, F. J., and Morgan, G. B., "Atmospheric Sureillance: The Current State of Air Monitoring Technology," Environmental Science and Technology, August 1971, pp. 678-684.

METEOROLOGICAL MEASUREMENTS

I. Introduction

The meteorological requirements for air quality assessment studies are data on wind speed, wind direction, air temperature, atmospheric stability, humidity, solar radiation, and mixing height. Since meteorological measurement systems are present in most urban regions, the first step is to determine what measurements are being made and what information facilities are available. Visibility measurements can aid in interpretation of air quality information and may be obtained.

The parameters measured and quantity of data needed for air quality modeling are related to the type of model to be used. For some applications, as in the use of climatological dispersions models which produce seasonal and annual mean air quality estimates, historical data can be used, i.e., wind speeds, directions, etc., of the preceding five years to obtain long-term frequency distributions. Such information can be obtained from the appropriate meteorological record center. The comparison of predicted air quality levels with the observed concentration, however, requires that corresponding meteorological information must be applied.

II. Instrumentation and Techniques

Among the many wind instruments used for measuring wind flow (speed and direction), the most common are cup and propeller anemometers. These instruments, although rugged, and durable, have limited sensitivity at very light wind speeds. For areas where very light winds are prevalent, instruments having photocells to detect the frequency at which a light beam is interrupted provide greater accuracy. For most applications standard anemometers are suitable, since they are designed to operate for long periods with little maintenance. Surface air temperature is routinely measured by a thermograph. The vertical temperature profile is derived from balloon-borne temperature sensors (radiosondes) that transmit radio signals of the environmental temperature while ascending. They are released twice daily (0000 and 1200 GMT) from a worldwide network of meteorological stations. Although the expense of radiosonde equipment precludes its operation in many communities, an estimate of mixing height can be interpolated from measurements taken at neighboring stations.

Atmospheric stability cannot be measured directly. Practical indirect methods, similar to that devised by Pasguill and adapted by Turner, make use of readily obtainable meteorological data. Parameters such as wind speed, cloud cover, cloud height, and the local time of day are related to atmospheric stability class. These measurements are made routinely for weather forecasts and can be procured on computer cards from local meteorological offices. Another approach in determining atmospheric stability is to measure wind speed and temperature on instrumented meteorological towers. From these values one can compute a Richardson number, which can be used to determine atmospheric stability class. This method is expensive and difficult to operate; hence, the indirect estimation technique is generally preferable.

The minimum mixing height over urban areas is generally estimated by considering how much the nocturnal urban air temperature is increased by the city heat island effect. As it traverses across urban areas, the lower layer or air is heated by the city creating a shallow mixing layer. This nocturnal mixing layer is on the order of 100 meters even on mights when strong temperature inversions are found up-wind of the city.

Dispersion models incorporate mixing height by specifying how the mixing height varies throughout the day between the extremes of nocturnal and afternoon values. In the climatological dispersion models, mixing height is generally specified as a function of stability class.

Recent interest in urban air pollution is certain to encourage development of advanced instrumentation for probing the urban atmosphere. Indirect sounding systems will allow continuous scanning of the lower atmosphere to determine changing temperature structures. A laser-radar system now under development should greatly enhance the understanding of urban pollution.

III. Supplemental Stations

The meteorological measurements already available may not always adequately represent the area's conditions. This is especially true of wind data. If the terrain is such that wind speed and direction measured outside the city does not adequately indicate the urban wind patterns, additional instrumentation within the city is necessary.

Both wind and surface temperature sensors require carefully selected locations with open exposure. The distance between the instruments and any obstruction should be a minimum of ten times the height of the obstruction. The thermograph should be situated over a grassy area andnot over concrete surfaces.

REFERENCES

1. Middleton, W. E. K. and Spilhas, A. F., 1963, "Meteorological Instruments," 3rd edition, University of Toronto Press, Toronto, Canada.

2. Turner, D. C., 1964, "A Diffusion Moedl for an Urban Area," Journal of Applied Meteorology 3(1); 83-91.

3. Slade, D. H., 1968, "Meteorology and Atomic Energy," Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia, TID-24190.

4. Holzworth, G. C., 1971, "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States," To be issued as an Environmental Protection Agency publication.

5. Mount, W. D., A. C. Amory, C. V. Weik and C. M. Maloy, 1968, "Capabilities of Millimeter Wave Radiometers for Remotely Measuring Temperature Profiles Pertinent to Air Pollution," Final Report SRRC-CR-68-19, Sperry Rand Research Center, Sudbury, Mass.

6. Johnson, W. B., 1971, "Lidar Measurements of Plum Diffusion and Aerosol Structure Conference on Air Pollution Meteorology of the AMS in Cooperation with APCA," April 5-6, 1971, Raleigh, North Carolina.

AIR QUALITY MODELING

Computer models are developed to provide a mathematical relationship between air pollution emission sources and the resulting level of air quality. These models allow the evaluation of various proposed air pollution abatement strategies for immediate and near-term problems, e.g., up to say, five years.

Models which have been developed and employed with varying degrees of success to date describe the dilution and dispersion of stable pollutants using the Gaussian distribution formula along with other empirical parameters. The major factors which influence pollutant dilution and dispersion are (1) atmospheric stability, (2) mixing height, (3) wind speed, and (4) direction. The major differences between the various Gaussian distribution models which are being employed are (1) averaging time of the prediction, (2) level and sophistication of input data and assumptions, and (3) computer storage and computational time.

The prediction of sulfur oxide and particulate long-term averages using diffusion modeling over regional areas have been in use for some time. These models have been used in assessing environmental impact, developing air quality implementation plans and projecting future air quality.

The modeling of carbon monoxide presents a different situation: Instead of predicting annual average, the averaging times of interest are, for example, 1 and 8 hour concentrations; instead of typical point and area sources carbon monoxide is emitted primarily from line sources; and, in addition to regional concentrations CO levels must also be predicted for local situations, i.e., street canyons. Only recently have carbon monoxide models been developed to predict region-wide concentrations. Current work includes line source, regional and sub-regional models designed to yield short and long-term averages. Many of these models, however, have not been fully tested at this time.

Concentrations of the pollutants entering into or resulting from photochemical reactions (hydrocarbons, oxidants and oxides of nitrogen) are much more difficult to predict. Although considerable work has been done, it appears that working models for these pollutants are yet a year or so away.

The application of even an adequately evaluated and tested model to a particular situation may present substantial difficulties. Major differences in topography as well as meteorology between the areas in which the model was tested and that under consideration, may require substantial modification of the model to suit the area under consideration. Extreme conditions may preclude the use of existing models and require that a pecial model be developed.

The various models which have been employed to date are summarized in Table 6. The regional assessment studies for sulfur oxides and particulates undertaken as a part of the pilot study employed different variaitons of the basic model. The details of the data and computer requirements are described in detail in separate publications. The major steps involved in modeling are illustrated in Figure 7.

TABLE 6

CHARACTERISTICS OF URBAN DISPERSION MODELS FOR STABLE POLLUTANTS

Model Type	Application	Emission Data Required	Aerometric * Data Required	Results	Computer Requirements
Calder 1970	1. Urban Planning 2. Abatement strategic formulation	Seasonal emission rate by source	24 - hour sampling at fixed intervals or continuous	Annual and seasonal averages	110 K bytes 30 min. per run
Fortak 1969	1. Urban Planning Abatement strategic formulation	Seasonal emission rate by source. Frequency distribution of space heating emissions.	30 minute averaging time	Frequency distributions of annual and seasonal concentrations. 30 minutes averaging time.	same as above
Johnson 1969	1. Predicting line source poll. input mobile source	Hourly emission rate along source line	Continuous	--	50 K bytes 15 min. per run

* Standard recorded wind speed, direction, mixing depth, temperature are analyzed to suit the model being used.

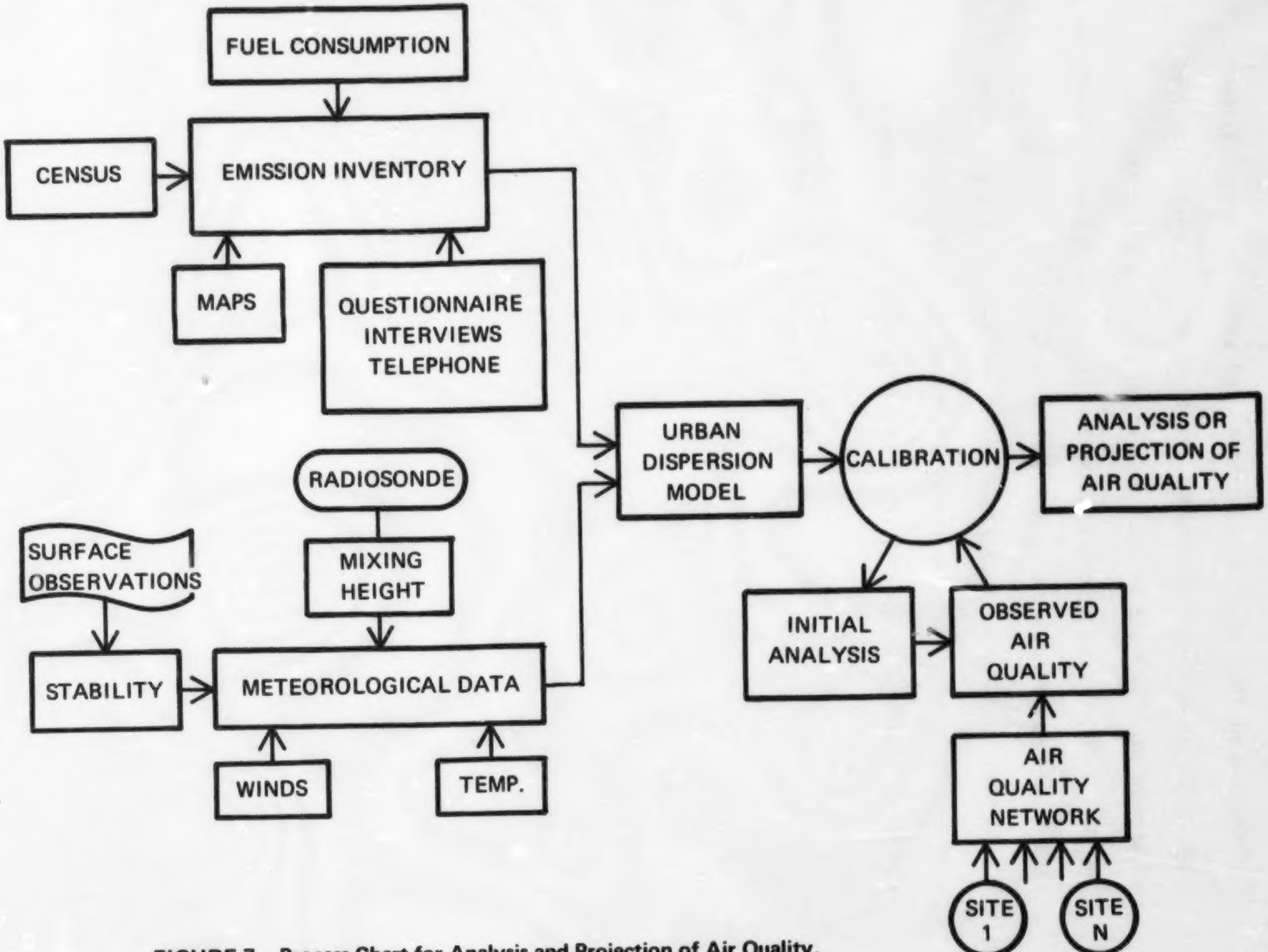

FUEL CONSUMPTION
CENSUS
EMISSION INVENTORY
MAPS
QUESTIONNAIRE
INTERVIEWS
TELEPHONE
RADIOSONDE
SURFACE
OBSERVATIONS
MIXING
HEIGHT
STABILITY
METEOROLOGICAL DATA
WINDS
TEMP.
URBAN
DISPERSION
MODEL
CALIBRATION
ANALYSIS OR
PROJECTION OF
AIR QUALITY
INITIAL
ANALYSIS
OBSERVED
AIR
QUALITY
AIR
QUALITY
NETWORK
SITE
1
SITE
N

FIGURE 7. Process Chart for Analysis and Projection of Air Quality.

Because of the numerous assumptions and estimates that must be made in the development of a model and in modeling a particular area adjustment must be made in the model using actual air quality data. For this reason it is necessary that actual air quality measurements be made in the application of an air quality model.

It must be stressed that research in the field of air pollution modeling is being pursued so rapidly in so many places that any statement of the state-of-the-art could be outdated in a matter of months.

REFERENCES

1. Calder, K. L., 1969, "Some Miscellaneous Aspects of Current Urban Pollution Models," Symposium on multiple-source urban diffusion models, University of North Carolina, Chapel Hill.

2. Calder, K. L., 1970, "A Climatological Model for Multiple Source Urban Air Pollution," report presented at the first meeting of NATO/CCMS Panel on Modeling held in Frankfurt, Germany, October 9, 1970.

3. Fortak, H., 1969, "Numerical Simulation of Temporal and Spatial Distribution of Urban Air Pollution Concentrations," Symposium on multiple-source urban diffusion models, University of North Carolina, Chapel Hill.

4. Johnson, W. B., Ludwig, F. L., and Moon, A. E., "Development of a Practical Multi-Purpose Urban Diffusion Model for Carbon Monoxide," presented at the sumposium on multiple-source urban diffusion models, University of North Carolina, Chapel Hill.

5. Miller, M. E. and Holzworth, G. C., 1967, "An Atmospheric Diffusion Model for Metropolitan Areas," APCA Journal, Vol. 17, No. 1, January 1967.

6. Worley, F. L., 1971, "Mathematical Modeling for Photochemical Smog," report to NATO/CCMS Modeling Panel Meeting held in Paris, France, July 26-28, 1971.

PROJECTIONS OF AIR QUALITY

I. Introduction

The adequate forecast of air quality requires that information be developed which describes the concentration of the pollutant and how it varies with space and time. Such forecasts may be derived through the use of "working" air quality models and adequate projections of future emissions. Meteorological information, one of the two inputs into the model, is generally assumed to remain unchanged over the projection interval. The key to successful predictions, therefore, is a detailed inventory of emissions projected for the year or years of concern.

This section describes the general approach to be taken in projecting emissions. Since the mechanics for translating emission estimates into air quality concentrations is identical to those used for modeling of existing air quality, it is not repeated in this chapter.

II. Emissions Projections

A standardized procedure for projecting emissions cannot be set forth due to the extreme variability of input information. In some urban areas very extensive and detailed plans have been made which may be used directly in estimating their impact on the region's air quality. For example, extensive transportation studies provide information on future traffic flow; master planning agencies in some areas have developed information relating to housing requirements, industrial zoning and the like. For other urban regions very little, if any, projections have been made. These cases require the making of numerous assumptions.

Projecting air pollutant emissions requires that some forecasts must be available or made concerning the following:

(1) Total population and its distribution

(2) Industrial activity

(3) Fuel use (quantities, quality and patterns)

(4) Transportation activity

(5) Solid waste generation and disposal

(6) Degree and extent of air pollution control

For most of urban regions, some information on the items will have been compiled and evaluated by experts in the appropriate fields. Thus, information on population growth, which has been developed for most urban areas in the world, is obtainable from planning organizations. Likewise, where transportation studies have been made, projections of future transportation demands and expected traffic flows are generally available. Forecasts of industrial activity are continually made by manufacturing associations or governmental agencies (departments or ministries of commerce, development and labor). The role of the individuals making projections is therefore to research and obtain what forecasts are available, and to blend these forecasts while incorporating their own judgments on the expected changes in emission characteristics.

For areas where none or very few projections of activity levels have been made or are available, rough forecasts of future emissions may still be made using various forecasting techniques. Although admittedly rough, such forecasts are useful in comparing control alternatives and in guiding future development. The minimum requirement in making emission projections is an adequate current emission inventory and forecasts of future population. This information together with historical trend data and information on natural resources, can be used to derive future emission patterns. A procedure for making such estimates is outlined in the next several paragraphs.

Projecting emissions from fuel consumption in stationary sources for a metropolitan area requires that certain considerations of the following type have to be made:

(1) What will be the total energy demand for each consumer category (i.e., residential, commercial-governmental, industrial, steam-electric power)?

A good approximation can be made through the development of per capita demands. An investigation of historical trends can reveal how this per capita demand is changing.

(2) Are major shifts in fuel use and/or quality likely?

The availability of resources, economic forecasts, and pollution regulation effecting types of fuels are the major items to be sought out. Again historical patterns may provide additional information.

(3) What will be the extent and efficiency of air pollution control?

This is directly related to any proposed or existing legislation.

(4) What will be the effect of changing technology on emission rate of pollutants (new boiler design)?

Increased efficiency of boilers or improved production can alter emission rates. Engineering calculations can provide information on what emission factors need to be revised.

For solid waste disposal activities questions on the following topics should be asked:

(1) What will be the total per capita generation of solid wastes?

More than likely this quantity will be based on extrapolation of historical data on increasing per capita rates along with information on use of consumer goods, increases in industrial activity and so on.

(2) How will the waste be disposed?

Current disposal methods may be extended to the future. However, current or proposed legislation may curtail certain activities, e.g., ban on open burning, thus assumptions on expected methods may have to be made.

Emissions from transportation sources can be estimated by the following techniques.

(1) What will be the total travel requirements for the city in the future?

The population planning bureau or zoning commission can provide information on total population density and expected growth. This coupled with historical trends on increased usage of motor vehicles should provide a good indication of the total travel requirements that can be anticipated.

(2) How will this travel be distributed with respect to space and time?

The projected population density and land use will be an adequate indicator of motor vehicle density. Historical data and trends could show the expected variability with respect to time.

(3) How will emission rates change for motor vehicles?

The installation of exhaust control devices or changes in the gasolines used can affect emission rates from vehicles. An indication of this may be derived from proposed legislation concerning emissions requirements.

Projecting emissions from industrial processes is the most difficult. In most cases the assumption is made that current practice will be the same in the future with natural increases due to population growth and increased demand for consumer goods.

APPENDIX A - ASSESSMENT OF AIR QUALITY IN ANKARA, TURKEY

INTRODUCTION

To demonstrate and document a procedure for performing air quality assessment studies as a part of the systems approach to abating air pollution, the CCMS Working Group on Air Pollution chose one city for study in each of the pilot and co-pilot countries. Ankara, Turkey, was selected as one of the three cities; Ankara has a history of serious air pollution problems caused by unique physical and meteorological conditions and by domestic heating methods that utilize low-quality fuels.

Although studies on Ankara's air pollution began as early as 1926, no regulatory legislation has been passed to deal directly with the problem. Prior to the NATO/CCMS Project, however, four major studies directed toward air pollution abatement were supported by the Scientific and Technical Research Council of Turkey (TBTAK). The first study involved the briquetting of coal to reduce particulate pollution. A new process is being developed at the laboratories of the Mineral Research and Technical Institute, and the project is now in the pilot-plant stage. The second study involves district heating of Ankara. The third study is directed toward improving boilers. The fourth study concerns standardization of monitoring methods. In addition to these four studies, the Turkish Coal Administration and the Electric, Gas and Bus Administration are conducting parallel studies that deal with coal briquetting and district heating, respectively.

With these studies already in progress, the initiation of the NATO/CCMS Assessment Study of Ankara gave new impetus to the city's fight against air pollution. The Ankara study began in March 1970, when the Working Group met in Ankara and outlined the four-point study. The first phase of the study, completed in fall 1971, concerned the assessment of sulfur oxide and particulate pollution. The assessment of the primarily automotive generated pollutants--hydrocarbons, oxides of nitrogen, carbon monoxide--was the subject of Phase II of the study. This phase of the study started in October 1971, was completed in August 1972.

An air quality monitoring network was started in September-October 1970 with the installation of sulfur dioxide and particulate measuring devices. For the purposes of Phase I study, samples were collected during the maximum heating season, from October 1970 to March 1971. A carbon monoxide monitor was installed in April 1971 followed by the development of ozone, hydrocarbon, and oxides of nitrogen measurement program in October 1971. The network is still being operated by the Turkish government to maintain surveillance of air quality. The model used in predicting air quality levels for particulates and sulfur oxides was developed by the CCMS Expert Panel on Air Pollution Modeling. Computer modeling of present and future conditions in Ankara for these pollutants was performed from April to June 1971, following collection and analysis of meteorological measurements and air quality data. Modeling of carbon monoxide, oxidants, and oxides of nitrogen was not included in the study.

The Scientific and Technical Research Council of Turkey (TBTAK) had overall responsibility for the CCMS Air Pollution Study in Ankara. Several other national and municipal agencies participated in the study; chief among these was the School of Hygiene of the Ministry of Health and Social Affairs and the General Directorate of Meteorology, which aided TBTAK in conducting the air quality monitoring program in Ankara. The other agencies are mentioned in various sections of this appendix, which presents detailed descriptions of each element of the air quality assessment of Ankara, including procedures and results.

DESCRIPTION OF STUDY AREA

The Ankara study area (Figure A-1) consists of the four subprovinces which comprise the city of Ankara. The approximate population for 1969 was 1,170,000 living in an area of 250 square kilometers. Figure A-2 shows the population density of the city.

Ankara is situated in a basin on the Anatolian Plateau. With the exception of the westerly direction, the city is completely surrounded by hills between 1000-1200 meters high. The old town around which modern Ankara has grown is located on a hill 980 meters above sea level. The lowest part of Ankara is 810 meters above sea level. The areas with the highest population density are in the lowest parts of the city.

Average atmospheric pressure in Ankara is 814 mb. Deviations from this average are not common in summer months, but in wintertime large pressure changes occur. January is the coldest month with an average monthly temperature of 1°C and August is the warmest with an average temperature of 23°C. In autumn daily temperature decrease occurs gradually, resulting in a long season. Spring is much shorter, with winter rapidly turning into summer.

Prevailing winds are mainly from the northeast and secondarily from the southwest. They are generally light and are mountain-to-plain breezes blowing in the early morning and at night. During the winter, temperature inversions, accompanied by thick fogs are quite frequent. Strong inversions may occur twice a day.

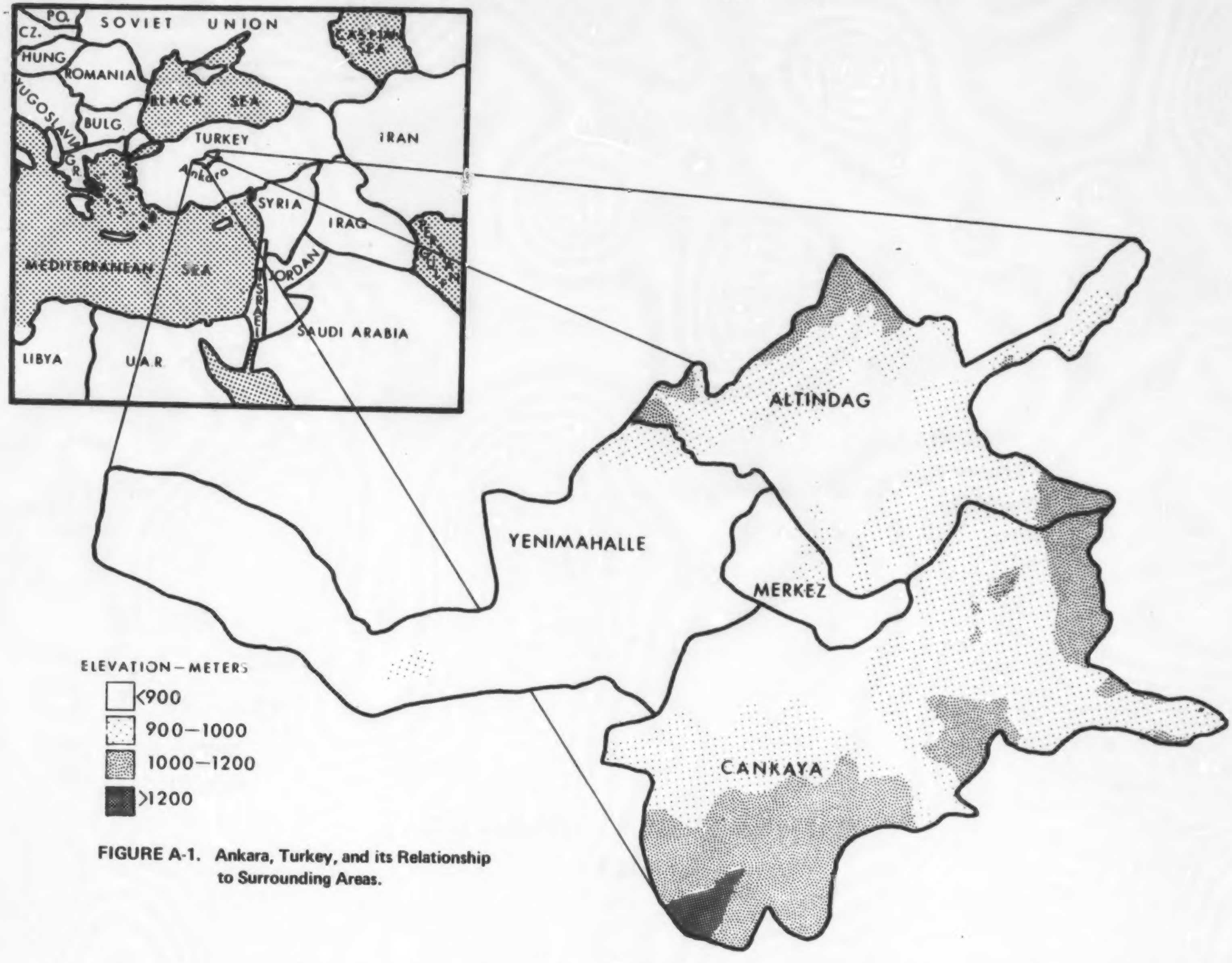
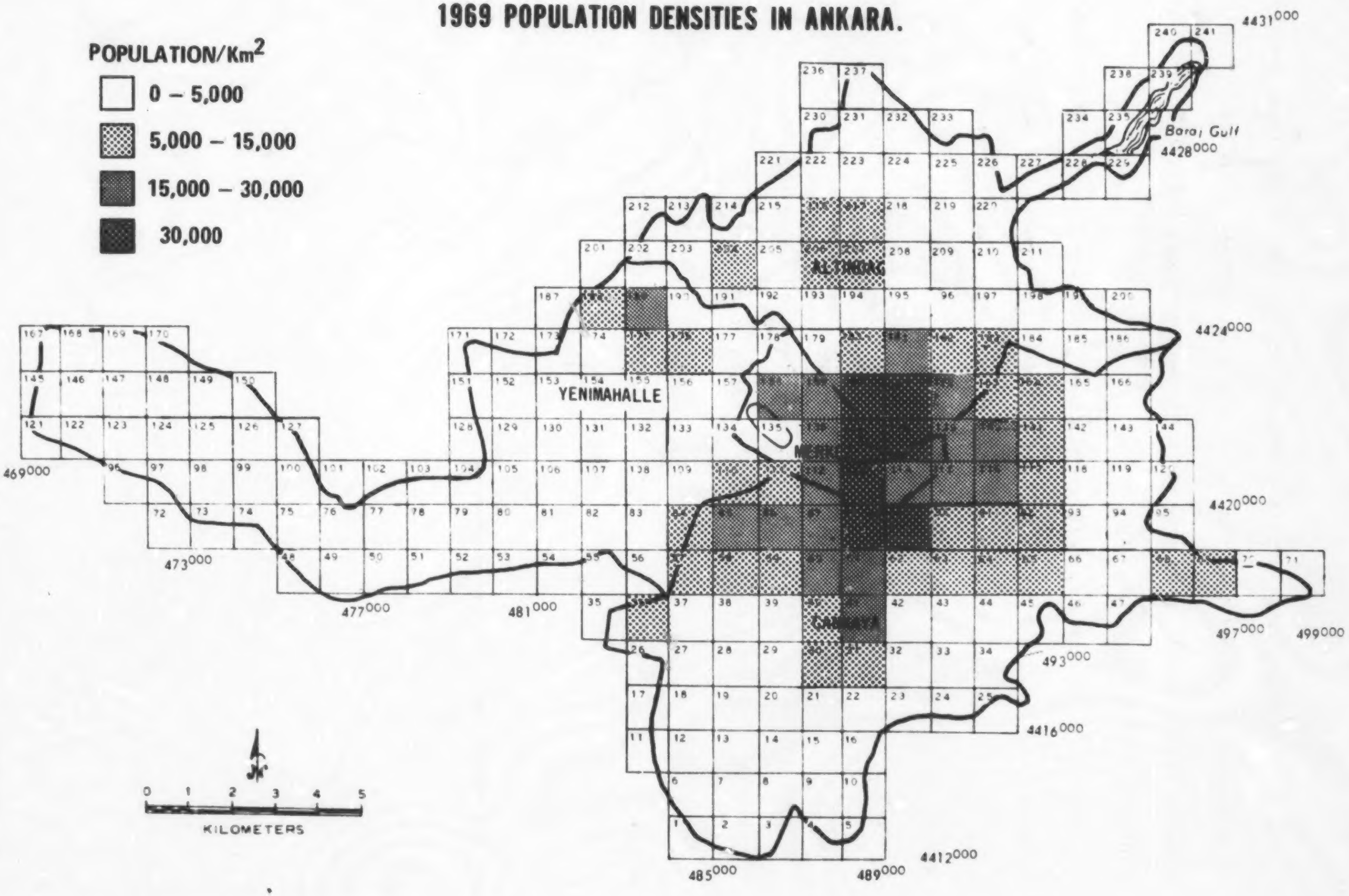

P.O.
CZ.
SOVIET UNION
CASPIAN SEA
HUNG
ROMANIA
YUGOSLAVIA
BLACK SEA
BULG
G.R.
TURKEY
IRAN
Ankara
SYRIA
IRAQ
MEDITERRANEAN SEA
JORDAN
ISRAEL
SAUDI ARABIA
LIBYA
U.A.R.
ALTINDAG
YENIMAHALLE
MERKEZ
CANKAYA
ELEVATION—METERS
<900
900—1000
1000—1200
>1200

FIGURE A-1. Ankara, Turkey, and its Relationship to Surrounding Areas.

FIGURE A-2

1969 POPULATION DENSITIES IN ANKARA.


POPULATION/Km^2
☐ 0 – 5,000
▨ 5,000 – 15,000
▨ 15,000 – 30,000
■ 30,000
YENIMAHALLE
ALTINDAG
MERKEZ
CANKAYA
Baraj Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0 1 2 3 4 5
KILOMETERS

Approximately 60% of Ankara's inhabitants reside in small tenements with the remaining 40% residing primarily in apartment buildings. Central heating is limited to about one-half of the apartment buildings--serving a population of less than 200,000.

Ankara is the administrative center of Turkey. It is characterized by a multitude of governmental, institutional and commercial buildings with industry being of secondary importance. The industry present in Ankara is typically that needed to meet its requirements. In order of priority, it includes: (1) food, (2) carpentry, (3) printing, (4) plastic and rubber forming, (5) foundries, (6) metal furniture manufacturing, (7) agricultural machinery, (8) construction, and (9) mining.

The major activity of Ankara is related to providing government services for the city and the nation. This is illustrated in Table A-1, where employment for the year 1965 is summarized by major work categories.

TABLE A-1

EMPLOYMENT CHARACTERISTICS OF ANKARA

(1965 Census)

Category	Number of People Employed in Ankara	Percent of Total
A. Miscellaneous Services		
1. Labor Union Centers and other professional unions.	700	0.3
2. Social Aid Services	700	0.3
3. Governmental Services	29,000	11.3
4. Legal Services	3,400	1.3
5. Health Services	7,700	3.0
6. Education Services	11,900	4.6
7. Military Services	49,500	19.3
8. Other Services	33,500	13.0
TOTAL	136,400	53.1
B. Construction Work	31,400	12.2
C. Trade		
1. Wholesale	5,000	1.9
2. Insurance	1,600	0.6
3. Banks	10,100	3.9
4. Small Scale Sales	17,200	6.7
5. Other Commercial Business	200	0.1
TOTAL	34,100	13.3
D. Manufacturing Facilities (Industry)		
1. Petroleum and Petroleum Products	400	0.2
2. Machinery (Excludes Electrical Machinery)	400	0.2
3. Printing	2,800	1.1
4. Furniture Making and Upholstery	2,300	0.9
5. Food and Beverages	7,800	3.0
6. Others	28,500	11.1
TOTAL	42,200	16.4
E. Agriculture	12,100	4.7
F. Mining	600	0.2
TOTAL	256,800	

SOURCES AND EMISSIONS

I. Introduction

A necessary element of air pollution assessment studies is quantitative information on sources of air pollutants and their rates of emission. To provide this information for Ankara, a complete emission inventory was conducted in the fall of 1970. The mobile source portion was updated and refined in the second phase of the study. The procedures used and the results obtained are summarized in this section of the report. The data presented are for the year 1969-1970. Emissions were estimated individually for each of the point sources and collectively for the multitude of other sources, such as road vehicles and residences. The geographical location of points of emission was identified according to a grid coordinate system. In addition to annual totals, emission estimates were also made for summer and winter seasons and in the case of carbon monoxide for 1-hour and 8-hour maximum.

Emissions were estimated by use of various indicators such as fuel consumption, refuse burning rates, vehicle kilometers, production data, and emission factors that relate these indicators to emission rates. The factors represent average emission rates for a particular source category. Since inherent differences among indidual sources cannot always be considered, discrepancies between the actual and estimated emissions are more likely with individual sources than with the total emissions for a source category. Emissions were apportioned into the grid system (Figure A-3) as described in the following section on inventory procedure.

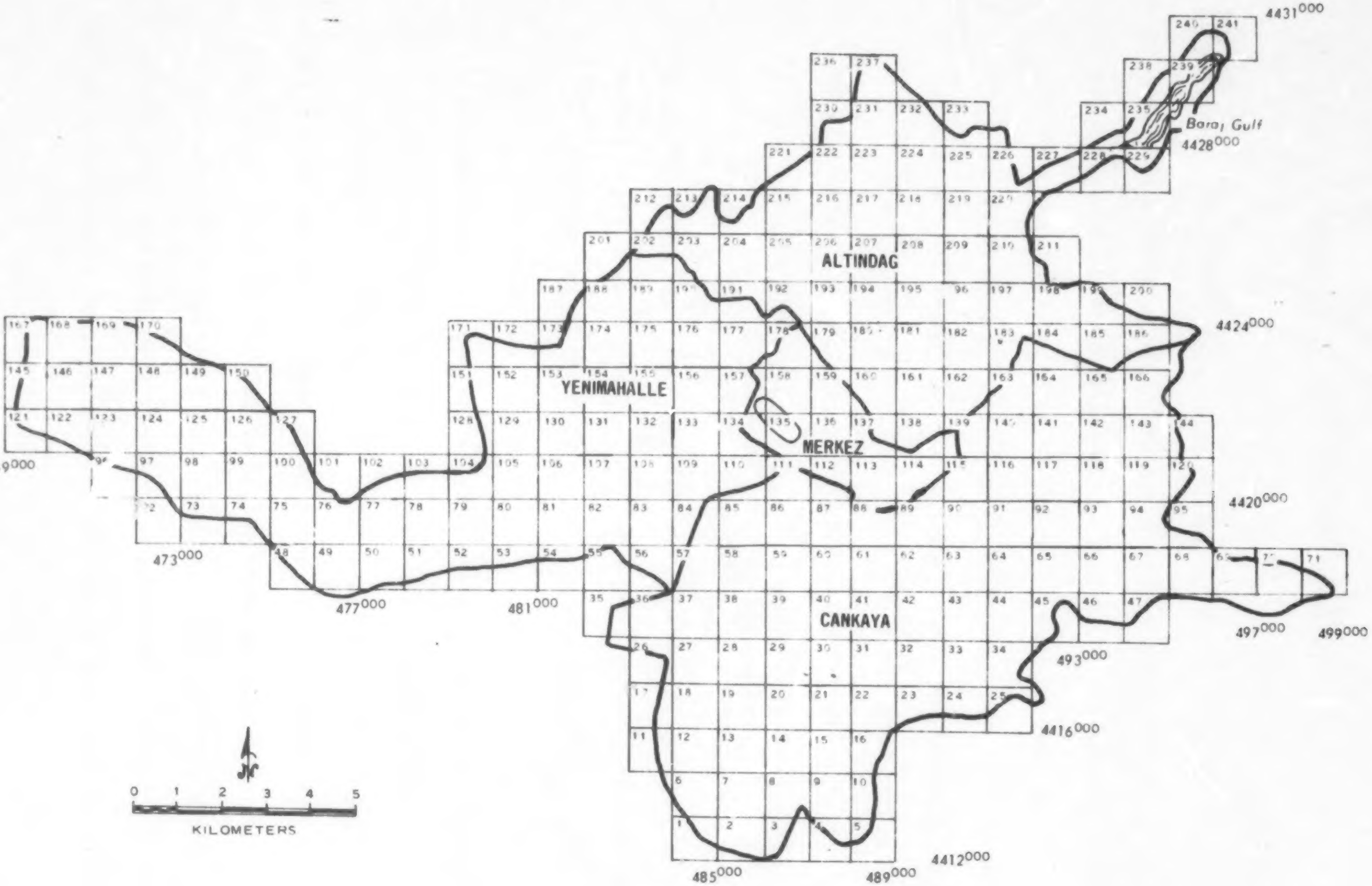

Baraj Gulf
ALTINDAG
YENIMAHALLE
MERKEZ
CANKAYA
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0
1
2
3
4
5
KILOMETERS

FIGURE A-3. Ankara emission inventory grid system.

As in all emission surveys, the data presented are estimates and should not be interpreted as absolute values. The estimates are in some cases partial totals because of limited data on emission factors and on production or consumption. Despite these limitations, the emissions data presented here are of sufficient accuracy and validity to define the extent and distribution of the air pollution emissions in Ankara.

II. Inventory Procedure

The Ankara emission inventory was conducted according to the procedure outlined in the Rapid Survey Technique. The choice of this technique was influenced primarily by two factor--time constraints and the nature of pollution sources in Ankara. In accordance with the deadline established for Phase I of the Ankara study, the inventory for particulates and sulfur oxides was to be completed in about a 3-month period. This limitation precluded a more detailed survey. Also, extensive questionnaire procedures were not required because of the relative absence of industry in Ankara. Most of the major point sources were governmental installations, on which information could be readily obtained from the appropriate government agency. These data were supplemented with field visits to selected major industries in the area.

Due to time constraints, the inventory of carbon monoxide, hydrocarbons, and oxides of nitrogen, conducted during Phase I of the study, used only readily available information for road vehicle emissions. During Phase II of the study, the mobile source inventory was substantially refined using the basic principle of the Rapid Survey Technique. A comprehensive assessment was not possible because of the unavailability of exhaust data for vehicles operating under Ankara driving conditions and the shortage of traffic volume information.

The sources were classified into five categories: (1) stationary fuel combustion, (2) transportation, (3) refuse disposal, (4) industrial processes, and (5) evaporative losses; sources were further subdivided into point and area sources. Facilities that emit large quantities of air pollutants were considered individually as point sources. They were located precisely, and emissions are reported individually for each. A total of 169 point sources were identified in Ankara. The many remaining pollutant contributors, such as motor vehicles and residences, were considered collectively as area sources. Emissions from these, identified according to each of 241 grids, were estimated by a variety of techniques.

The information sought in the survey included fuel consumption rates, fuel quality, refuse generation rates, refuse disposal practices, motor vehicle statistics, certain industrial production rates, and residential heating practices. The principal sources of these data are summarized in Table A-2.

A. Fuel Combustion in Stationary Sources. The problem of determining fuel use patterns in a city such as Ankara is quite complex. Different fuels of extremely variable quality are used to satisfy the energy demands of the city. Preparing an inventory of emissions requires not only that the amounts of each fuel used be determined, but that its use be assigned geographically according to the established grid coordinate system. In Ankara, this was accomplished as follows:

TABLE A-2

SOURCES OF DATA FOR THE ANKARA EMISSION INVENTORY

Category	Source of Data
AREA SOURCES	
1. *FUEL COMBUSTION*	
Fuel quantities	MTATKI, and Ministry of Energy and Natural Resources
Fuel quantities	MTA
Combustion conditions	Oktay Erenturk (Private consultant to TBTAK)
Stack parameters	Master Plan Bureau, Oktay Erenturk
2. *SOLID WASTE DISPOSAL*	
Quantities	Office Assistant Mayor
Disposal Methods	Office Assistant Mayor
3. *POPULATION*	
Total	Master Plan Bureau, State Statistics Institute
Distribution	Master Plan Bureau
4. *TRANSPORTATION*	
Fuel quantities	Ministry of Energy and Natural Resources
Fuel quantities	MTA
Distribution	TBTAK, Master Plan Bureau
POINT SOURCES	
1. *FUEL COMBUSTION*	
Government buildings	Ministry of Energy and Natural Resources
Industries	Personal visit, TBTAK
Other	
2. *INDUSTRIAL PROCESSES*	Personal visit, TBTAK
3. *SOLID WASTE*	Assistant Mayor of Ankara

(1) The total quantity and the average quality of the fuels used in the Study Area were determined according to consumer category (governmental, industrial, etc.).

(2) The amounts of the different fuels used by each point source were determined and assigned to exact locations.

(3) The amount of each fuel used by area sources was obtained by difference.

(4) The fuels used by the area sources were "distributed" among the grids primarily on a population density basis and for industrial sources by use of existing land use data.

In Ankara, coal and fuel oil are the primary fuels. The coal, which includes coke, lignite, and sub-bituminous coals, is sold and distributed by the government and private dealers. Detailed accounts are kept on the government sales by the Ministry of Energy and Natural Resources, which provided the requisite information for the inventory, i.e., area-wide consumption totals and geographical distribution. The private dealers were canvassed individually to determine the information on the private sales of coals.

Comparable information was not available for fuel oil. The only statistics that could be obtained were the usage totals for the entire Province of Ankara. In an extrapolation, it was assumed that 85% of the fuel oil consumed in the Province was burned within the study area. This assumption warrants further investigation.

Gas, obtained in Ankara as a byproduct from coking operations, is used almost exclusively for cooking and other household purposes. The requisite information was supplied by the producers, the Principal Gas Works. Estimates concerning the consumption of wood were obtained from the General Directory of Forestry.

Among the 150 individual largest consumers of fuels in Ankara are 80 governmental buildings and 2 industries. The Ministry of Energy and Natural Resources provided fuel consumption rates for government facilities, and individual factories were consulted for the others. That Ankara is notably void of large point sources is evidenced by the fact that less than 25% of all fuels are consumed by the 150 largest users. The task of determining where the remainder (75%) of the fuels are burned in Ankara was the most difficult. In order to develop a means for apportioning the fuels among the over 240 grids, the MTA conducted a survey, consisting of personal interviews with building managers. These interviews were conducted in areas surrounding the monitoring sites. The survey revealed that all fuels are being burned throughout the city and that zones where only coal or fuel oil is burned do not exist. This finding corroborated the expressed opinions of knowledgeable individuals. The fuels were therefore "allocated" to the individual grid zones on a population basis. The fuels used in industries were "allocated" to the industrial zones as shown by the land-use maps prepared by the Master Plan Bureau.

Another task in calculating emissions was to determine seasonal differences in consumption rates. Since fuel usage for process heating in factories and shops does not change significantly from season to season this usage was assumed constant. Space heating, however, depends on the ambient temperature, and changes in consumption rates can be computed on that basis.

B. Fuel Combustion in Mobile Sources. Road vehicles and locomotives were the two source types considered under this category. The basic data used for calculating road vehicle emissions consisted of total gasoline sales in the area supplied by the Ministry of Energy and Natural Resources and vehicle flow information supplied by the State Highways General Directorate. The fuels consumed in locomotives, while operating within the boundaries of the study area, were obtained and apportioned to grids traversed by the railroad routes, with more weight assigned to the grids in the vicinity of railroad stations.

The estimation of road vehicle emissions involved the accomplishment of two tasks: (1) determination of vehicle travel in the area; and, (2) determination of the appropriate emission factors. The vehicle travel information of importance includes vehicle characteristics (weight, age, and manufacturer), the total distance travelled (vehicle-kilometers) and the average speed of travel. Since not all of this information was available, some simplifying assumptions were necessary.

The total travel (vehicle-kilometers per year) in the study area was determined from total gasoline sales coupled with an average fuel consumption rate (kilometers per liter). Two techniques then were used to determine the geographical distribution of travel within the study area. This was necessary since traffic count information was limited to only the central portion of the study area--the City of Ankara. For the purpose of apportionment to grids, the total vehicle-kilometers were divided between the City of Ankara and the outlying districts on a population basis. The travel outside the city was distributed to grids according to population. The travel within the city could be more accurately portrayed. The allocation to grids was prorated on the basis of measured vehicle miles in each grid. Vehicle miles are determined from traffic counts and roadway lengths.

A major input to emission calculations is information regarding the average speed of travel for the area for which the estimation is made--in this case the grid. Speeds on major thoroughfares were measured as part of the transportation study conducted by the State Highways General Directorate. These data were used in determining the average speed in each grid.

The type of vehicle strongly affects the quantity of pollutants discharged. Information is therefore necessary on the distribution of travel according to vehicular weight classes (light duty vehicles, heavy duty gasoline vehicles, and heavy duty diesel powered vehicles), age (model year), and manufacturer. The percentage of travel by vehicle weight class was obtained from the State Highways General Directorate. The division of heavy duty vehicles into gasoline and diesel sub-categories was estimated on the basis of diesel fuel consumption. The Ankara motor vehicle registration data was the source of information regarding vehicle age and manufacturer.

Because of the mixture of motor vehicles, e.g., American, English, German, and others in use in Ankara, and the limited emission test data available, the vehicle population was grouped into three categories: German, English and American. The vehicles from other countries were placed in the German and English categories. Emission test data were available only for these categories. The German and English test results were based on the Economic Community of Europe (ECE) test cycle; the American test results were derived from the 1972 Federal Test Procedure. The calculation of emissions required that adjustments be made to reflect the average speeds and the previously discussed vehicle characteristics.

The emission factors for heavy duty vehicles used in this study were derived from emission tests conducted in the United States. The speed-emission relationship for light duty vehicles was assumed to apply to heavy duty vehicles as well.

C. Solid Wastes. Since incineration of refuse or on-site open burning is not practiced to any degree in Ankara, the only information neede was the amount of waste material that is collected and burned in the city dump. Collection of refuse material is a function of the municipality. The Office of the Assistant Mayor estimated that about 145,000 tons of refuse was collected and disposed of in the city dump during 1969. This constituted about one-half of the total amount of refuse generated; the remaining half was either used for scrap, was noncombustible, or was left unburned. The dump was considered as a point source of pollution.

D. Industrial Processes. Information on the largest industrial processes was obtained by personal visit to each of the establishments. Only a total of 11 were thought to be significant as point sources of pollution. Ankara encompasses, however, a multitude of small factories and shops that do generate some emissions, which collectively could contribute substantially to the total. These were not included in the current survey.

III. Results

An estimated 58,000 tons of sulfur oxides, approximately 23,000 tons of partoculate matter, 73,000 tons of carbon monoxide, 13,000 tons of oxides of nitrogen and 16,000 tons of hydrocarbons were emitted to the atmosphere in Ankara in 1969-1970. The major source of these pollutants is the burning of fuels to heat governmental and institutional buildings, individual houses, apartment building and motor vehicle traffic. Emissions by source category are summarized in Table A-3.

A. Stationary Fuel Combustion. This category includes all fixed installations where fuels are burned for either space or process heating. The sources in this category are classified into (1) steam electric generating plants, (2) industrial plants, (3) residential housing, and (4) commercial, institutional and governmental facilities. This classification facilitates not only the estimation of emission rates but also the evaluation of the pollution problem and the selecting of control alternatives.

In 1969, the base year for the inventory, 722,900 tons of coal and coke, 400,000 tons of fuel oil and kerosene, 65 million cubic meters of manufactured gas, and 64,000 tons of wood were consumed in the Ankara area. Thus, in 1969, fuel oil and coal supplied the bulk of Ankara's energy demands (fuel oil 56% and coal 39%).

As shown in Table A-4, a wide variety of coals is being consumed in Ankara. The sulfur content, the ash content, and the heating values

TABLE A-3

AIR POLLUTANT EMISSIONS FROM ALL SOURCES IN THE ANKARA STUDY AREA, 1969

(10^3 Kg/yr)

Source Category	Sulfur Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
Transportation					
Road Vehicles	200	230	56,000	9,700	4,900
Other	620	240	600	480	710
Subtotal	820	470	56,600	10,180	5,610
Stationary Fuel Combustion					
Industry	10,900	4,870	120	90	1,570
Residential	18,430	7,470	9,010	1,890	1,480
Commercial — Institutional and Governmental	24,370	4,580	100	160	3,300
Electric Generation	1,060	1,210	30	20	230
Subtotal	54,760	18,130	9,260	2,160	6,580
Refuse Disposal					
Incineration	n	n	n	n	n
Open Burning	70	1,200	6,200	2,200	440
Subtotal	70	1,200	6,200	2,200	440
Industrial Processes	2,000	3,210	1,300	n	n
Evaporative Losses	—	—	—	1,820	—
GRAND TOTAL	57,650	23,010	73,360	16,360	12,630

n = negligible

TABLE A-4

CONSUMPTION OF FUELS IN STATIONARY SOURCES FOR THE ANKARA STUDY AREA, 1969

(tons)

Fuel Type	Residential Heating	Consumer Type				
		Commercial Institutional Governmental	Industrial	Industrial Process	Electric Power	TOTAL
Coals (official)						
Coke	130,000	4,000	6,000	—	—	140,000
Briquette	8,400	—	100	—	—	8,500
Bituminous	42,500	2,400	36,600	110,000	13,000	204,500
Lignite (Tuncbilek)	78,200	72,000	10,600	—	5,400	166,300
Lignite (O.A.L.)	14,000	16,000	14,600	10,000	12,600	68,100
Lignite (Seyitomer)	21,000	—	—	—	—	21,000
Coals (private)						
Lignite (Bolu)	10,000	—	30,000	—	—	40,000
Lignite (Gediz)	36,000	—	—	—	—	36,000
Lignite (Soma)	12,000	—	—	—	—	12,000
Lignite (Cicekdag)	1,000	—	15,000	—	—	1,000
Lignite (Low quality)	—	—	—	—	—	15,000
Fuel Oil (tons)	73,000	254,000	—	73,000	—	400,000
Kerosine (tons)	24,000	—	—	—	—	24,000
Natural Gas (M^3)	65×10^6	—	—	—	—	65×10^6
Wood (tons)	64,000	—	—	—	—	64,000

of the different types of fuels are summarized in Table A-5. It is important to note that although the majority of coals have sulfur contents of about 1%, a substantial fraction of the fuels contains 5 to 8 percent sulfur by weight.

Emissions attributed to the burning of fuels are given in Table A-6. The burning of fuel oil accounts for about 60% of the sulfur oxides emitted. For particulate matter, the burning of coal is the primary combustion source, accounting for nearly 80 percent of the total from the fuel consumption category. Electric power for Ankara is supplied from generating stations located away from the city. One small "peaking" power generating station, however, is located within the city and in 1969 burned a total of 31,000 tons of coal. The station is equipped with cyclone collectors.

B. Mobile Fuel Consumption. The emissions estimated to result from the use of motor vehicles, both gasoline and diesel powered, and from trains are summarized in Table A-7. Motor vehicles are the primary source of carbon monoxide and hydrocarbons, accounting for 76 and 59 percent, respectively. In addition, motor vehicles account for an estimated 39 percent of the total quantity of nitrogen oxides emitted.

In 1969, there were approximately 35,000 automobiles and 10,000 trucks and buses operating in the study area. Collectively, slightly more than 1 billion vehicle-kilometers are travelled annually. In 1969, nearly 100,000 tons of gasoline and 23,000 tons of diesel fuel were consumed in the area.

TABLE A-5

FUEL QUALITIES FOR THE ANKARA STUDY AREA, 1969

Fuel Type	Sulfur % by wt.	Ash, % by wt.	Heat Content cal / g.
Coals (official)			
Coke	0.6	20.0	5,400
Briquette	1.1	17.5	6,180
Bituminous	0.9	13.4	6,750
Lignite (Tuncbilek)	0.9	17.0	4,400
Lignite (O.A.L.)	3.0	14.0	3,200
Lignite (Seyitomer)	4.5	13.0	2,900
Coals (private)			
Lignite (Bolu)	8.0	14.3	5,300
Lignite (Gediz)	5.0	24.0	5,500
Lignite (Soma)	2.0	15.0	4,300
Lignite (Cicekdag)	5.0	17.0	4 000
Lignite (low quality)	6.0	20.0	3,500
Fuel Oil			
Residual No. 5*	4.0	—	10,000
Residual No. 6*	4.5	—	9,500
Kerosine	0.5	—	10,500
Wood	—	0.5	3,000
Natural Gas	—	—	4.2×10^6 cal / m^3

*Residual oil sulfur contents based on Turkish Petroleum Company sales.

TABLE A-6

EMISSIONS FROM FUEL COMBUSTION IN STATIONARY SOURCES IN ANKARA, 1969

(10^3Kg/Year)

Source	Sulfur Oxides	Particulates	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
Industry					
Coal	7,380	4,640	110	60	850
Fuel Oil	3,520	230	n	30	720
Residential					
Coal	12,000	6,330	8,840	1,770	880
Fuel Oil	6,400	160	80	50	190
Gas	n	20	30	10	90
Wood	30	960	60	60	320
Commercial - Institutional - Government					
Coal	2,070	3,760	100	50	720
Fuel Oil	22,300	820	10	110	2,580
Electric Generation					
Coal	1,060	1,210	30	20	230
TOTAL	54,760	18,130	9,260	2,160	6,580

n = negligible

TABLE A - 7

AIR POLLUTANT EMISSIONS FROM MOBILE SOURCES IN ANKARA, 1969

(10^3 Kg/yr)

SOURCE	fuel usage	SO_2	Particulates	CO	HC	NO_x
Gasoline–powered motor vehicles	105,000	100	180	55,220	9,517	4,040
Diesel–powered motor vehicles	23,000	100	50	780	130	860
Trains		620	240	600	480	710
Coal	15,300					
Diesel	5,400					
TOTAL		820	470	56,600	10,180	5,610

Motor vehicle travel and therefore emissions exhibit a very substantial diurnal variation. Peak traffic during the morning and afternoon "rush" hours give rise to high emission rates and accompanying ambient concentrations. For example, nearly 8 percent of the daily emissions from motor vehicles occurs between 0830 and 0930 hours. Similarly, nearly 52 percent of the daily emissions occur in an 8-hour period from 1145 to 1945 hours. These estimates are based on actual hourly counts at key intersections.

C. Solid Waste. The burning of refuse at the dump is a significant source of particulate matter. As shown in Table A-8 an estimated 1.2 million kilograms of particulate matter were added to the pollution load of Ankara from this source in 1969.

D. Industrial Processes. The study area includes relatively few industrial complexes. From an air pollution standpoint, the cement plant, the municipal gas factory, several small metal foundries, a grain silo, and an asphalt batching plant are the most significant sources of process emissions. Emissions from these sources are summarized in Table A-9.

The cement plant, located outside the downtown area, produced approximately 500,000 tons of cement in 1969.

Fuel oil supplies the process heat in the kilns. The kilns are equipped with electrostatic precipitators estimated to provide an average overall collection efficiency of 99 percent.

The municipal gas factory uses coal to make coke. The by-product gases are recovered and supplied to customers in the city as a cooking fuel. In 1969, approximately 110,000 tons of coal were used to generate

TABLE A-8

AIR POLLUTANT EMISSIONS FROM SOLID WASTE DISPOSAL, 1969

		Quantities (10^3 Kg/year) Emissions				
Disposal Methods	Waste	Sulfur Oxides	Particulates	Carbon Monxide	Hydrocarbons	Nitrogen Oxides
Open Burning						
Dumps	146,000	70	1,200	6,210	2,190	440
On-site	n	n	n	n	n	n
Incineration						
Municipal	0	0	0	0	0	0
On-site	n	n	n	n	n	n
TOTAL	146,000	70	1,200	6,210	2,190	440

n = negligible

TABLE A-9

AIR POLLUTANT EMISSIONS FROM INDUSTRIAL PROCESSES, ANKARA, 1969

(10^3 Kg/year)

Industry Type	Sulfur Oxides	Particulates	Carbon Monoxide	Hydrocarbon	Nitrogen Oxides
Cement	n	590	n	n	n
Asphalt	n	1,280	n	n	n
Foundries	n	70	1,300	n	n
Grain	n	1,260	n	n	n
Municipal Gas	2,000	n	n	n	n
Beer	n	10	n	n	n
TOTAL	2,000	3,210	1,300	n	n

n : negligible

80,000 tons of coke. Emissions of particulate matter from the process are small, since the gases are cleaned prior to distribution. The sulfur removed from the coke gas, however, escapes to the atmosphere during regeneration of the hematite.

A significant source of particulate matter is the asphalt batching plant. The daily manufacture of 200 tons of hot air asphalt generates about 3.5 tons of particulate emissions. No pollution control devices are installed at this plant.

E. Seasonal and Geographic Distribution of Emissions. The emission rates of particulates, oxides of sulfur, and oxides of nitrogen are very seasonal. As shown in Figures A-4 and A-5, the emission rate (tons per average day) in the winter season is about 14 times higher than during the summer season for sulfur oxides and five times in the case of particulate matter. Winter emissions for nitrogen oxides are about twice as great as summer emissions. Carbon monoxide and hydrocarbon emissions are distributed more evenly throughout the year. Figure A-6 gives the annual emission rates and percentages from each source category for nitrogen oxides, carbon monoxide and hydrocarbons.

The locations of the major point sources are shown in Figure A-7. Although some major sources are located in the periphery of the city, most of them are situated in the center of the city. For sulfur oxides and particulates this is further illustrated in Figures A-8 and A-9, which show the emission densities of these pollutants. Emission rates of more than 5 tons per square kilometer per day were estimated for the core area and decreasing with distance away from the city center.

Emission densities for oxides of nitrogen, carbon monoxide and

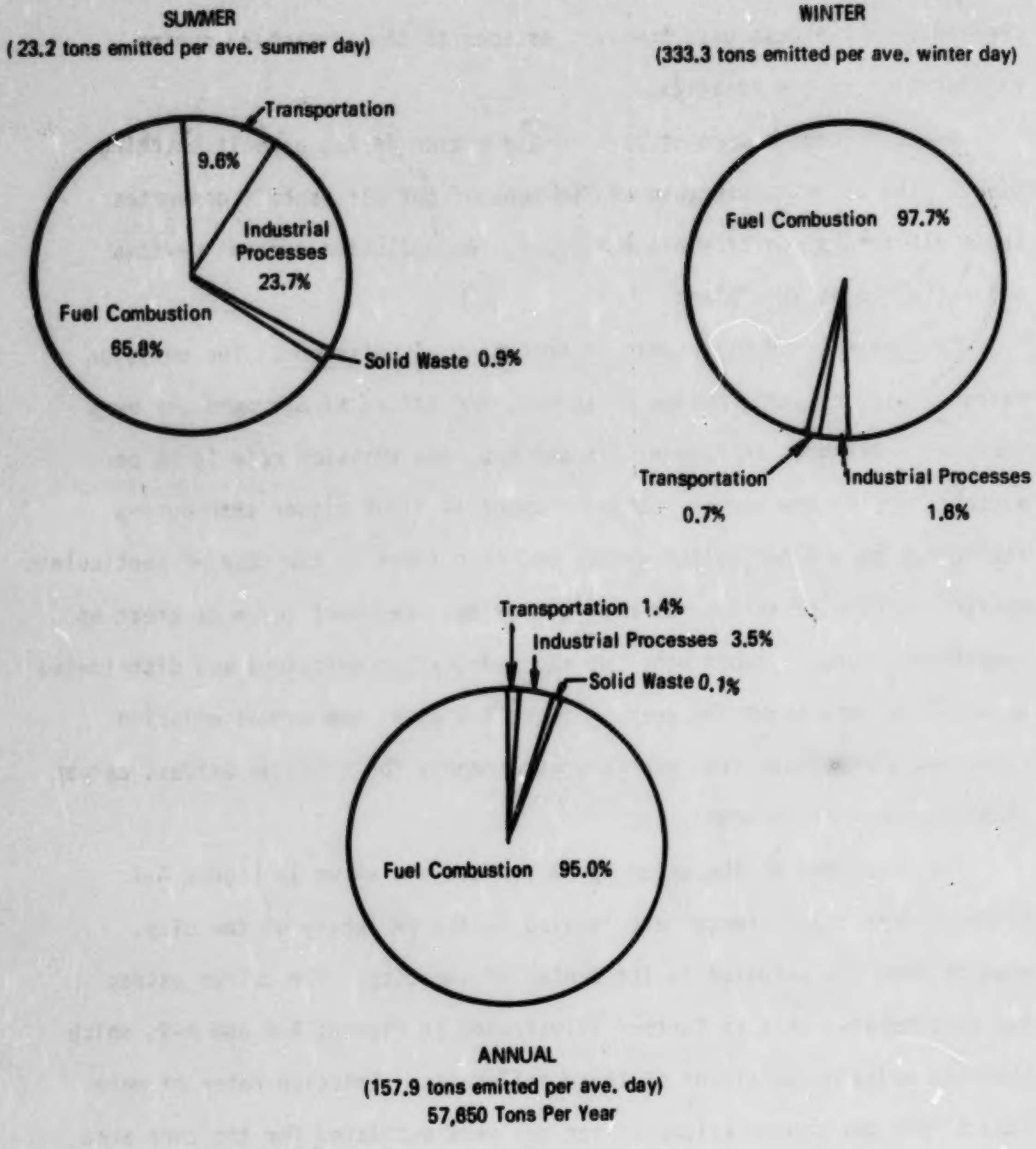
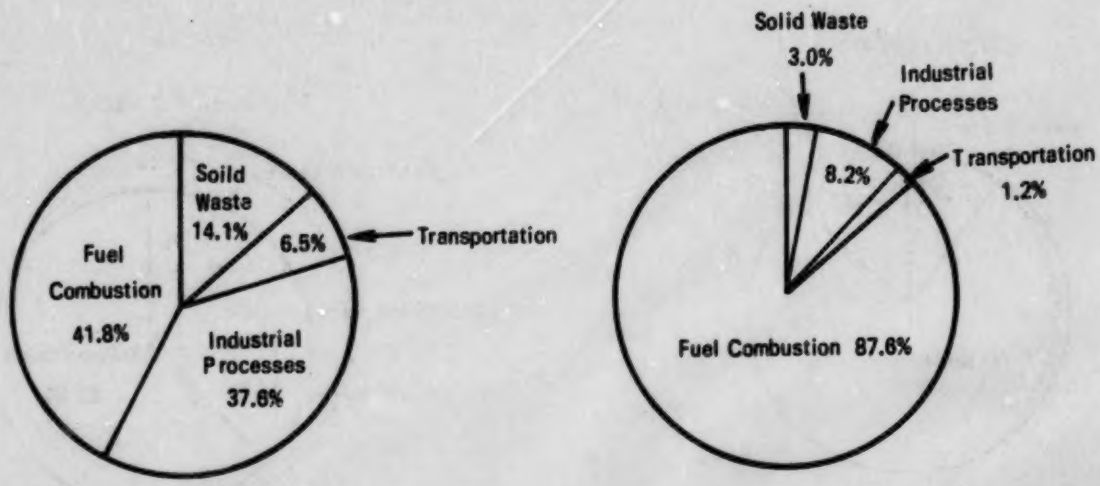
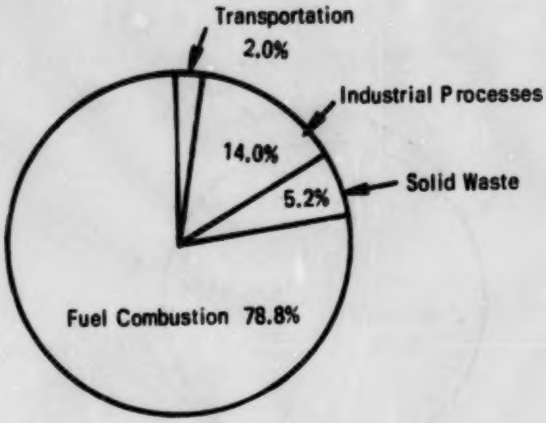


FIGURE A—4 Emmissions of Sulfur Oxides in the Ankara Study Area by Season and by Various Source Categories



SUMMER
(19.7 tons emitted per ave. summer day)

WINTER
(108.7 tons emitted per ave. winter day)



ANNUAL
(63.0 tons emitted per ave. day)

23,010 Tons Per Year

FIGURE A-5. Emissions of Particulates in the Ankara Study Area by Season and by Source Category.

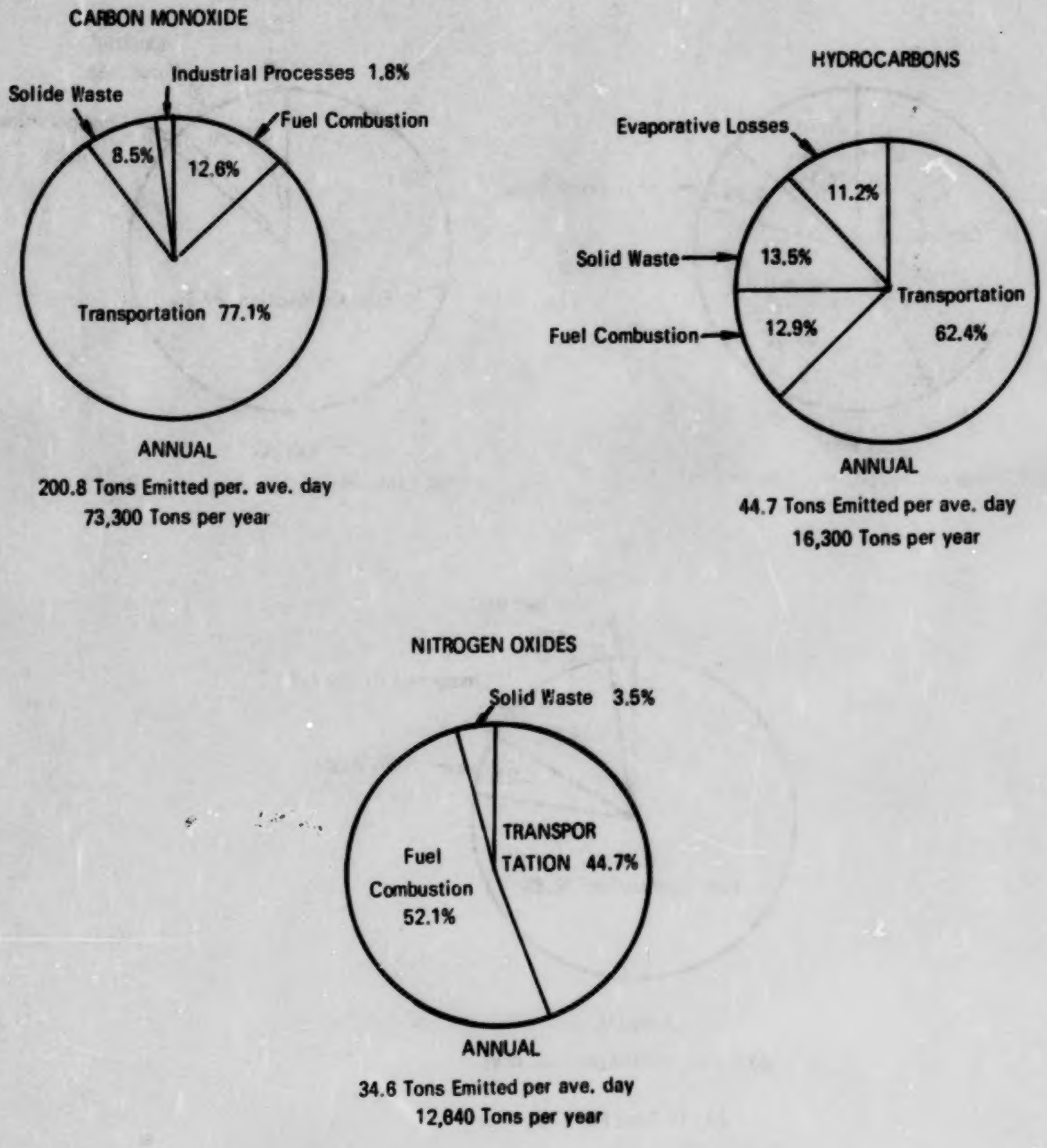


FIGURE A–6. Annual Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides in the Ankara Study Area by Source Categories.

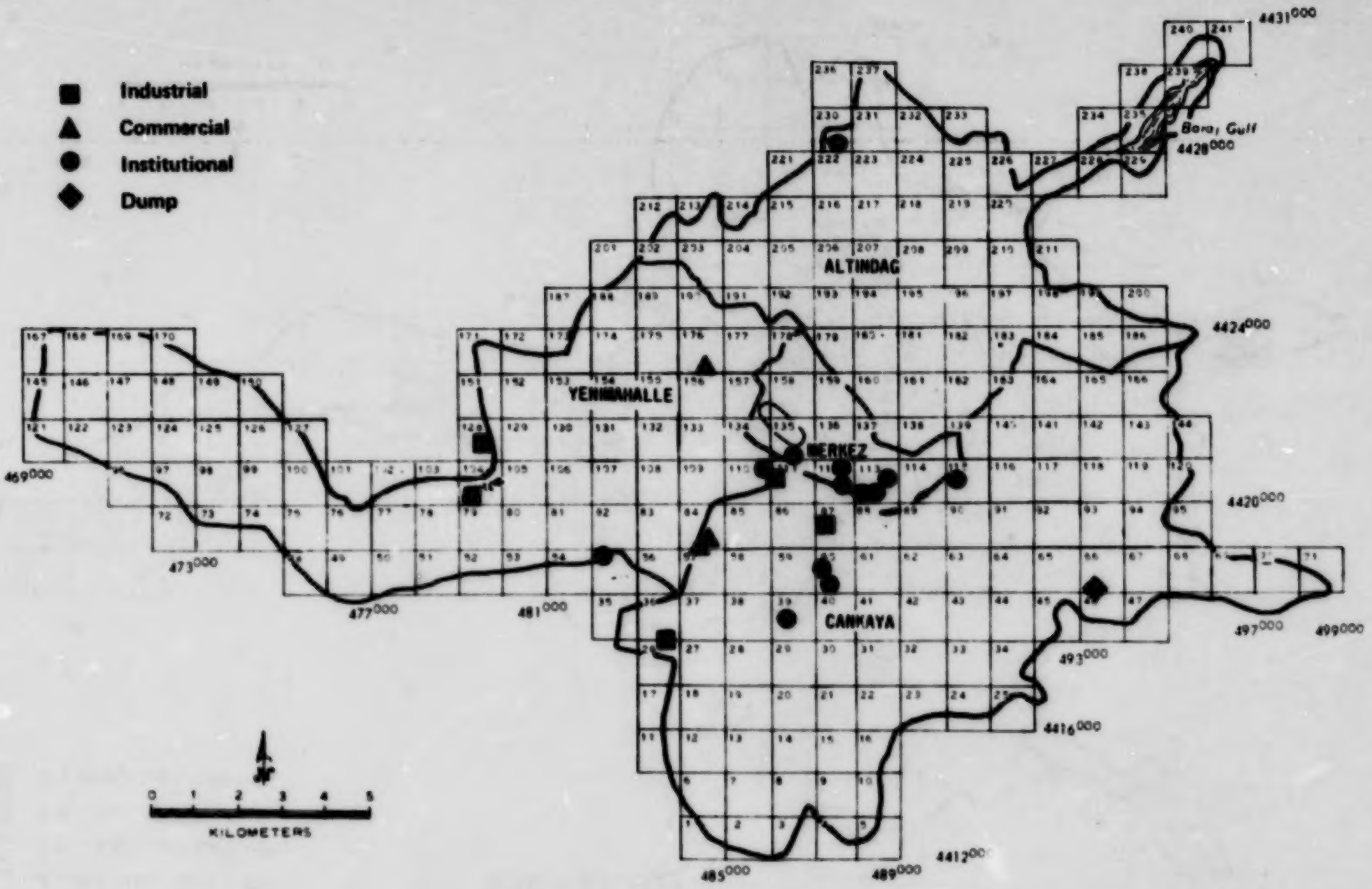

■ Industrial
▲ Commercial
● Institutional
◆ Dump
ALTINDAG
YENIMAHALLE
MERKEZ
CANKAYA
Bora, Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0
1
2
3
4
5
KILOMETERS

FIGURE A-7. Location of Major Point Sources in the Ankara Area.

FIGURE A-8
SULFUR OXIDE EMISSION DENSITIES IN ANKARA, YEARLY AVERAGE

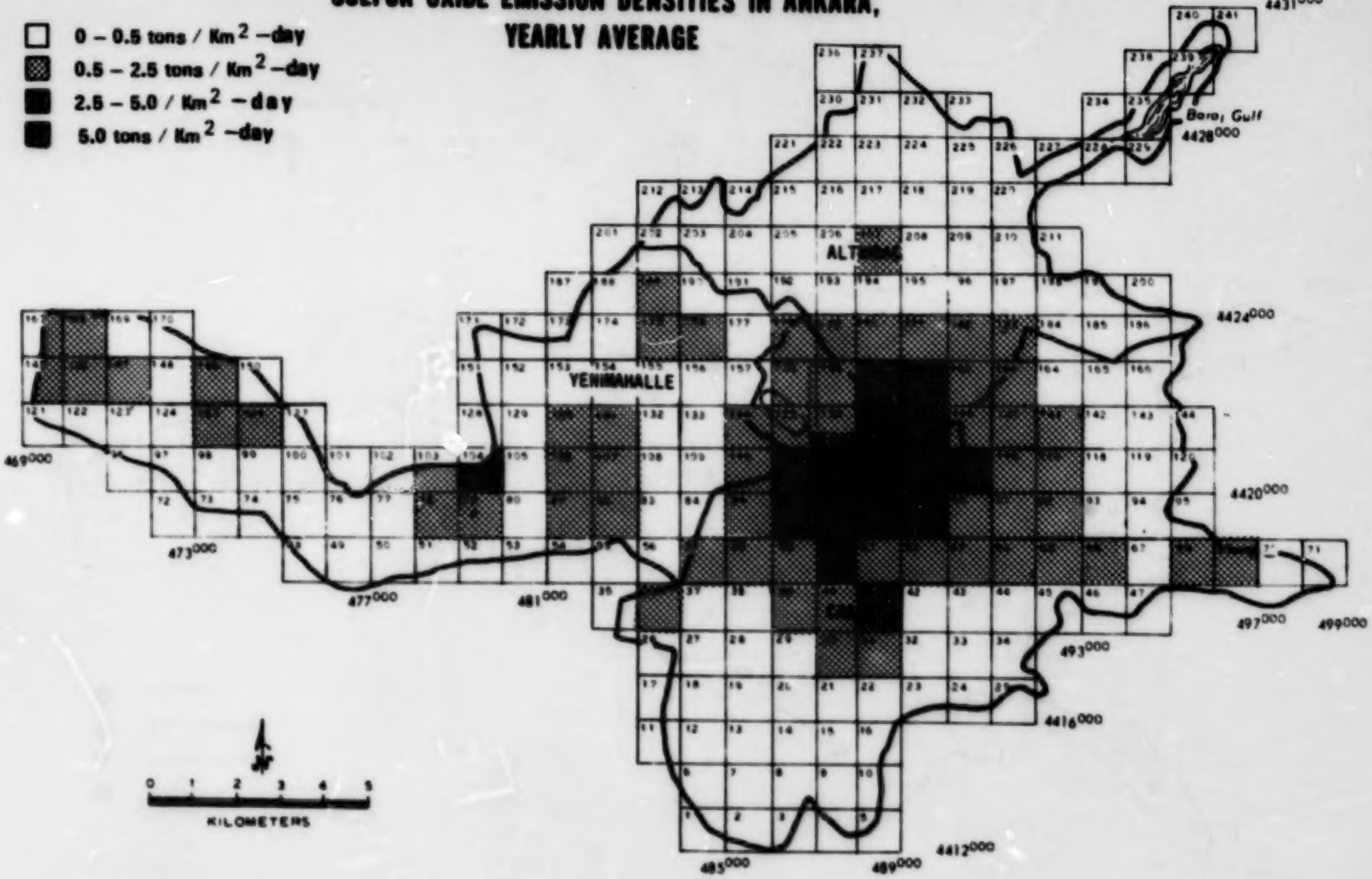
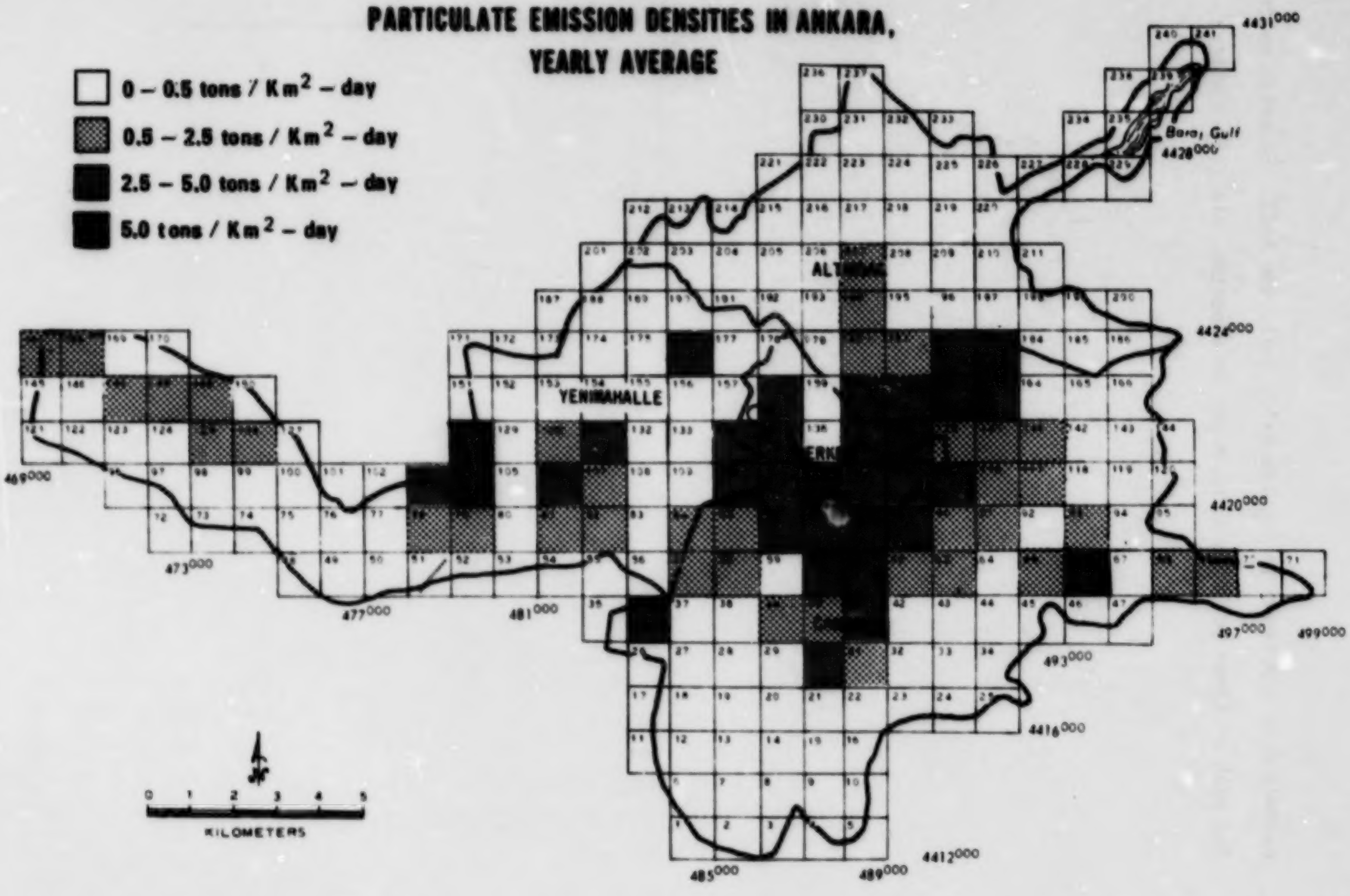

□ 0 – 0.5 tons / Km^2 –day
▨ 0.5 – 2.5 tons / Km^2 –day
■ 2.5 – 5.0 / Km^2 –day
■ 5.0 tons / Km^2 –day
YENIMAHALLE
ALT
Bora; Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0
1
2
3
4
5
KILOMETERS

FIGURE A-9

PARTICULATE EMISSION DENSITIES IN ANKARA, YEARLY AVERAGE



□ 0 – 0.5 tons / Km² – day
▨ 0.5 – 2.5 tons / Km² – day
■ 2.5 – 5.0 tons / Km² – day
■ 5.0 tons / Km² – day
ALTINDAG
YENIMAHALLE
Baraj Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0 1 2 3 4 5
KILOMETERS

hydrocarbons are shown in Figures A-10, A-11, and A-12. Emission patterns for each of these pollutants, as might be ex[illegible]ed, are very similar.

FIGURE A-10
CARBON MONOXIDE EMISSION DENSITIES IN ANKARA, YEARLY AVERAGE

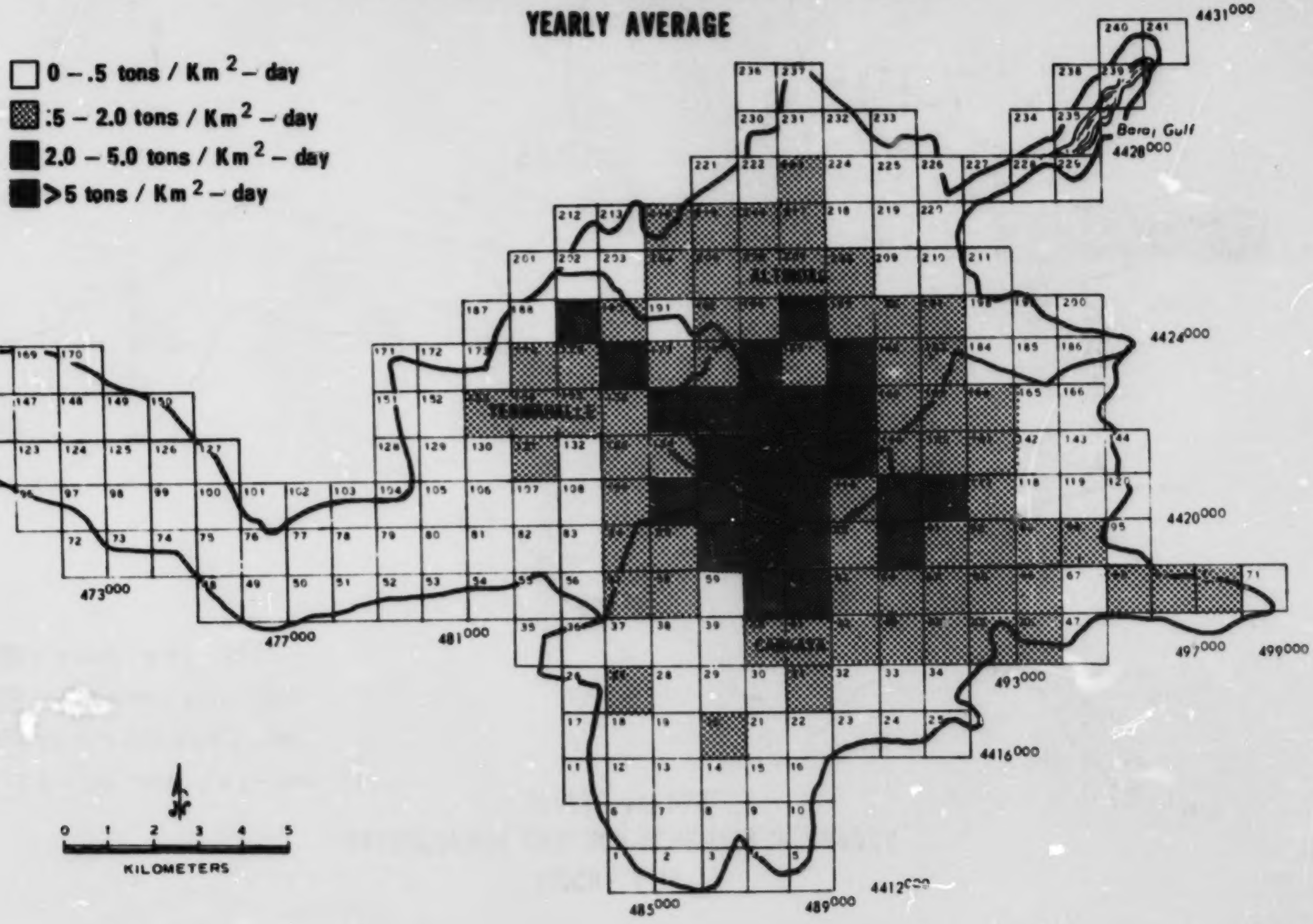

☐ 0 – .5 tons / Km 2 – day
▨ .5 – 2.0 tons / Km 2 – day
■ 2.0 – 5.0 tons / Km 2 – day
■ >5 tons / Km 2 – day
ALTINDAG
YENIMAHALLE
CANKAYA
Baraj Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0 1 2 3 4 5
KILOMETERS

FIGURE A-11
HYDROCARBON EMISSION DENSITIES IN ANKARA, YEARLY AVERAGE

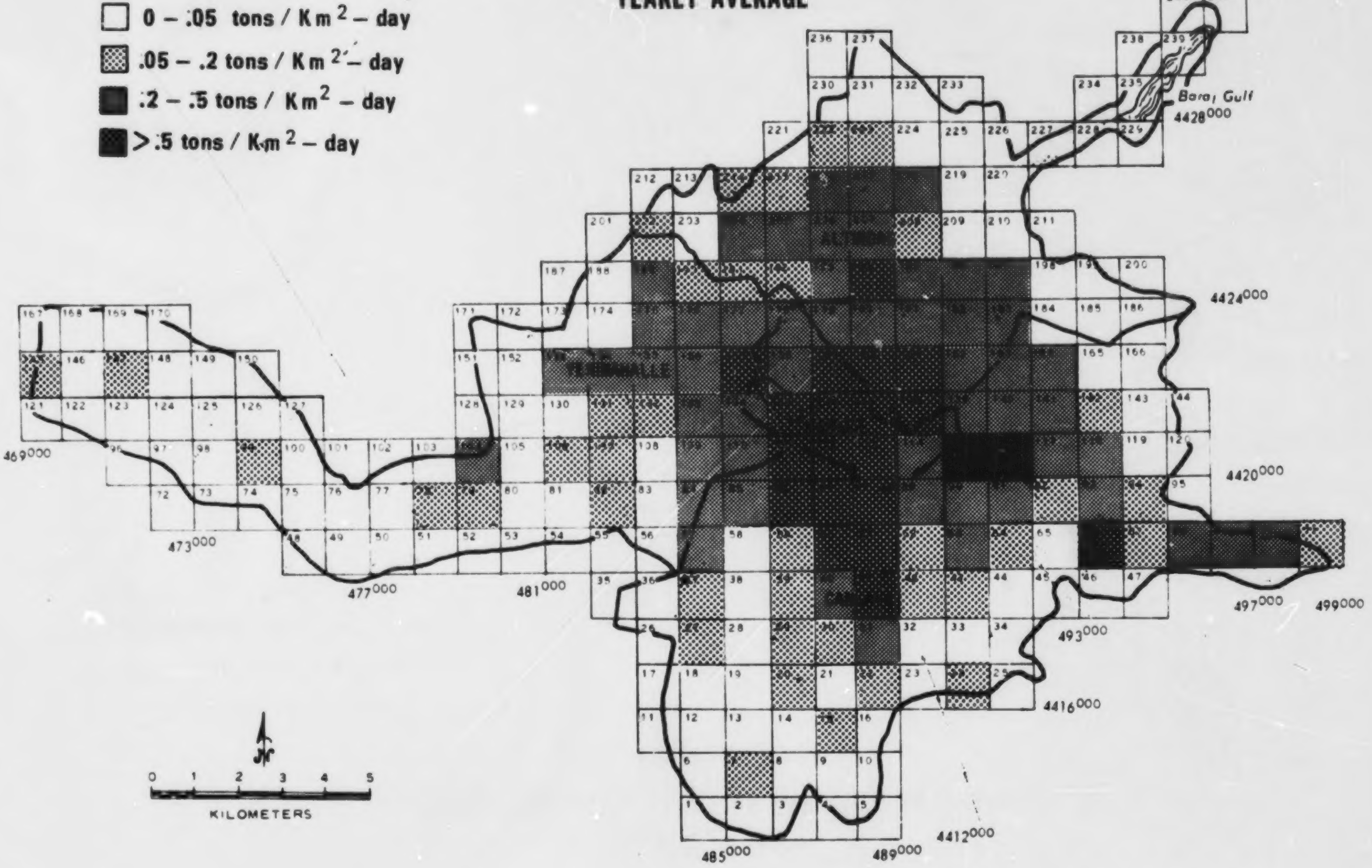
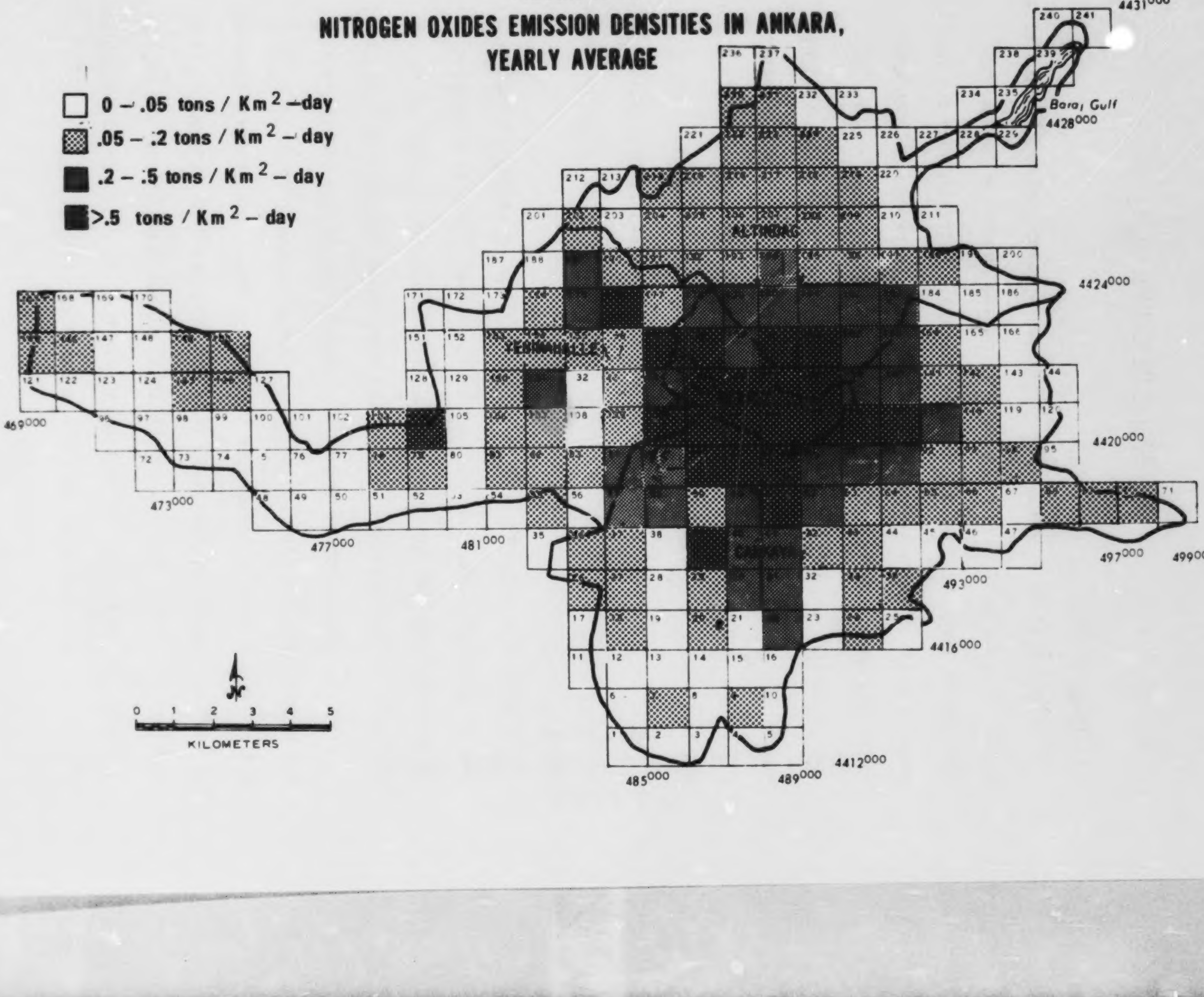

☐ 0 – .05 tons / Km^2 – day
▨ .05 – .2 tons / Km^2 – day
■ .2 – .5 tons / Km^2 – day
■ > .5 tons / Km^2 – day
Baraj Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
0 1 2 3 4 5
KILOMETERS

FIGURE A-12
NITROGEN OXIDES EMISSION DENSITIES IN ANKARA, YEARLY AVERAGE


☐ 0 – .05 tons / Km^2 – day
▨ .05 – .2 tons / Km^2 – day
■ .2 – .5 tons / Km^2 – day
■ >.5 tons / Km^2 – day
ALTINDAĞ
YENIMAHALLE
ÇANKAYA
Baraj Gulf
4431000
4428000
4424000
4420000
4416000
4412000
469000
473000
477000
481000
485000
489000
493000
497000
499000
N
0 1 2 3 4 5
KILOMETERS

AIR QUALITY MONITORING

I. Introduction

Assessment of an area's air pollution problem and application of a systems approach in developing and evaluating control alternatives require an adequate body of air quality data. Although some air quality measurements of both sulfur dioxide and total suspended particulates (TSP) had been made in Ankara before this study, further monitoring was required during Phase I to provide adequate geographical coverage and to increase the specificity of measurements. For these purposes, a completely new air quality monitoring network was designated, installed, and operated for sulfur dioxide and suspended particulates. During Phase II this network was expanded to include a monitoring station for carbon monoxide, total hydrocarbons, ozone, and nitrogen dioxide measurements.

The Ankara network consists of 13 stations, distributed throughout the metropolitan area. At each station, 24-hour integrated samples of both SO_2 and TSP were collected daily for subsequent laboratory analysis. Three stations also housed continuous SO_2 sampler-analyzers, to provide information on the hourly variability of SO_2 concentrations. The central station also included continuous instruments for HC, CO and ozone and 24-hour integrated sampler for NO_2. The primary sampling period for Phase I of the study (SO_2 and TSP) was from October 1, 1970, to March 31, 1971. Whereas for Phase II it was from October 1, 1971, to March 31, 1972. The collection of air quality data for all pollutants has, of course, continued past the primary sampling period.

This section of the report describes the design and operation of the air quality monitoring network and summarizes the air quality data.

Although air quality data for SO_2 and TSP presented in this report encompasses the period from October 1, 1970, to March 31, 1972, only the portion collected during the first phase, i.e., October 1, 1970, to March 31, 1971, has been analyzed and was used in the validation of the model.

It also briefly summarizes the previously collected air quality information, which was extremely valuable in selecting sampling sites and instruments.

II. Past Air Quality Data

Several investigations of the ambient air levels of sulfur dioxide and smoke in Ankara have been conducted during the past few years. Recently a set of measurements were made with the British-designed apparatus for estimating smokeshade and sulfur dioxide concentrations by a peroxide titrametric method. The results obtained at the Hygiene School during the period 1964 to 1966 showed an average concentration of 250 ug/m^3 for SO_2 and smokeshade levels in the range of 160 to 280 ug/m^3. In late 1969, a five station network reported that SO_2 values ranged from a low of 26 ug/m^3 in August to a high of 502 ug/m^3 in January; smokeshade averages ranged from 43 ug/m^3 in August to 496 ug/m^3 in December. Also, the University of Ankara has conducted an air pollution measurement study of SO_2 and particulate matter. Samples were collected during the winter season at six sites located throughout Ankara.

III. Network Design

The design of the new network entailed selection of equipment and methods of analyses, determination of the number and location of sampling sites, selection of sampling periods and frequencies, and determination of laboratory and data analyses and validation procedures. The overall objectives of the assessment phase of the study dictated the following requirements for collection of air quality data:

- Area-wide representation, including measurements in relatively unpolluted locations to determine "background" or baseline levels of pollutants
- Concurrent data at all sites for at least a 3-month period
- Methods consistent with those described in the pollutant criteria documents
- Because of a lack of resources only a single station would be used for Phase II pollutants

In addition, since initially only long-term diffusion models were to be developed and tested for Ankara, there was no immediate need for data of less than 24-hour averaging time. Integrated sampling could therefore suffice for both SO_2 and particulates.

A. Equipment and Methods. In addition to the requirements specified above, the selection of equipment and methods for the study was affected by specific conditions in Ankara:

- Since earlier measurements indicated remarkably high pollutant concentrations, monitoring equipment of an extremely high degree of sensitivity was not required for SO_2 and particulates. (No air quality data for other pollutants was available).

- Reliability of equipment was crucial, since extensive backup maintenance in terms of replacement parts or manufacturer representatives would not be readily available.

- Electrical operating parameters in Turkey (220 volts, 50 Hertz) imposed the requirement that equipment must be readily modifiable.

The Hi-Vol air sampler was selected as the sampling device for total suspended particulates. This sampler, shown in Figure A-13 consists of a filter holder for 8-by-10 inch glass-fiber filters, a vacuum pump for sampling at a rate of about 55 cubic feet per minute, and a wooden shelter. Modification of the pump was not required because the motors could operate on either 220 or 110 volts. The concentrations of TSP in ambient air are determined by gravimetric measurements. Supporting laboratory equipment includes an analytical balance and a humidity-controlled atmosphere. Since these were not available in Ankara at the time, the filters were pre-weighed and re-weighed (routinely) in laboratories in the United States during the first phase of the study. The Ankara laboratory was equipped with a balance in May 1971.

Three separate sets of equipment and sampling techniques were selected for measuring sulfur dioxide. Each station was equipped with impinger-type bubbler devices designed for collecting 24-hour samples; these samplers provided the basic SO_2 data for the study. Three stations

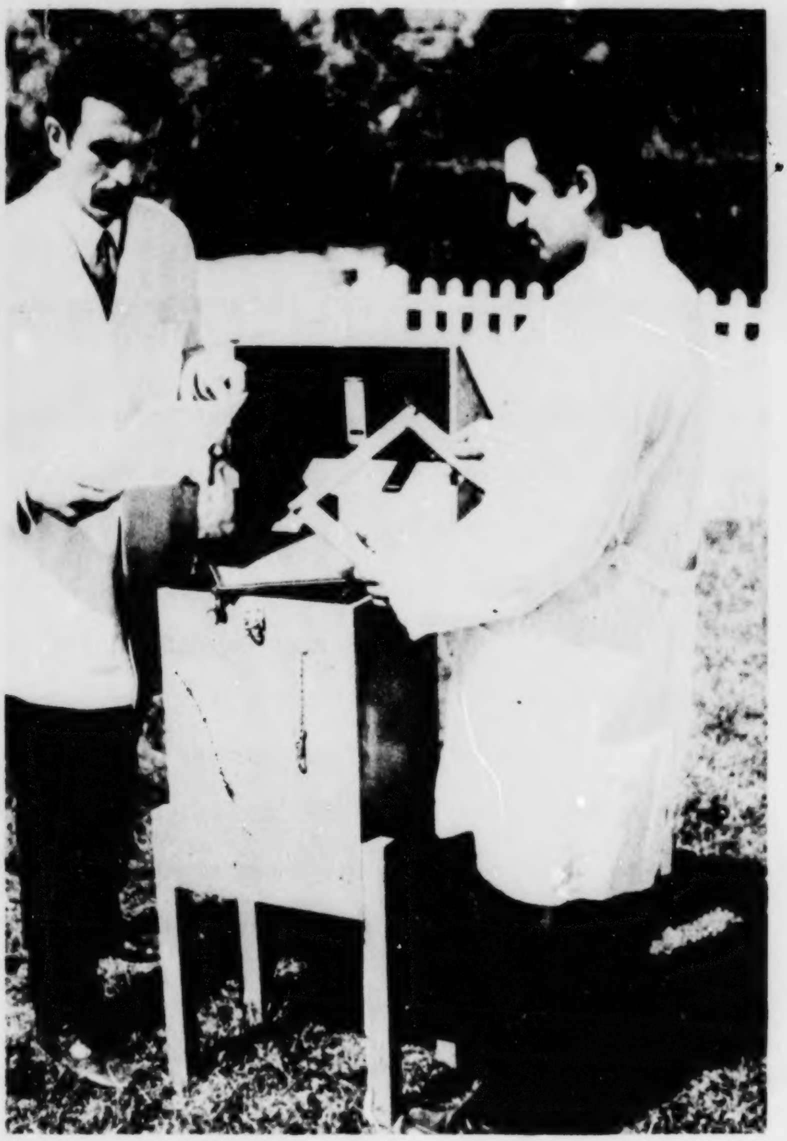


FIGURE A–13. High Volume Air Sampler.

were equipped with continuous SO_2 sampler analyzers (coulometric) to provide data on the hourly variations of SO_2 concentrations. Also, on an experimental basis, one station was equipped with a total sulfur analyzer to provide some indication of sulfur components other than sulfur dioxide in the air of Ankara.

The impinger-type bubbler device, shown in Figure A-14, consists of a membrane type pre-filter to remove particulate matter, a 50-ml polypropylene collection tube containing West-Gaeke absorbing solution, an orifice for controlling flow rate, a dry meter for measuring air volume, and a vacuum pump. The samples were analyzed in the laboratory using the West-Gaeke technique. Laboratory equipment consists of a spectrophotometer or a colorimeter, distillation and ion exchange equipment for preparing high-quality distilled water, and glassware.

The coulometric SO_2 analyzer specially adapted to operate at 220 volts, 50 Hertz, was chosen for continuous measurements because of its proven field reliability, ease of operation and maintenance, and relatively low cost. The coulometric analyzer, shown in Figure A-15, was dynamically calibrated in the United States and again in Ankara with sulfur dioxide permeation tubes before monitoring began. Concentrations of sulfur dioxide are automatically recorded on strip charts. Laboratory support includes calibration equipment and air measuring devices.

A single continuous total sulfur sampler-analyzer based on flame photometry was operated to provide preliminary data on the concentrations

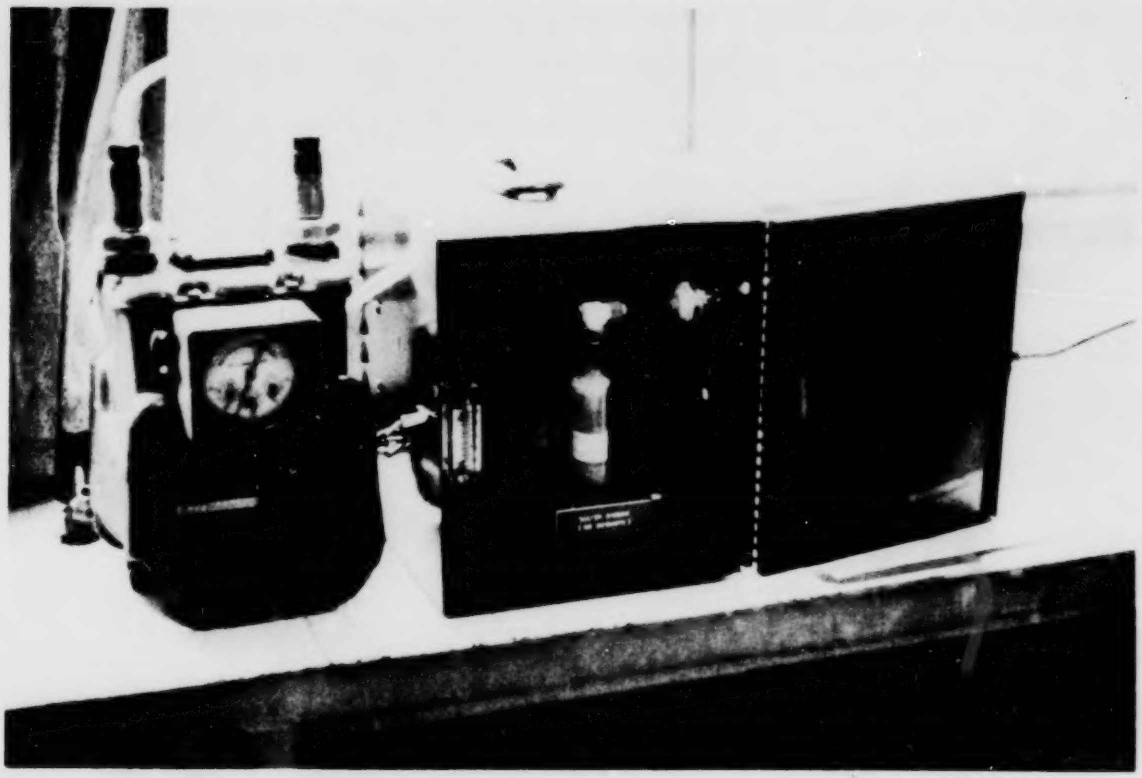


FIGURE A–14. INTERGRATED SULFUR DIOXIDE SAMPLER.

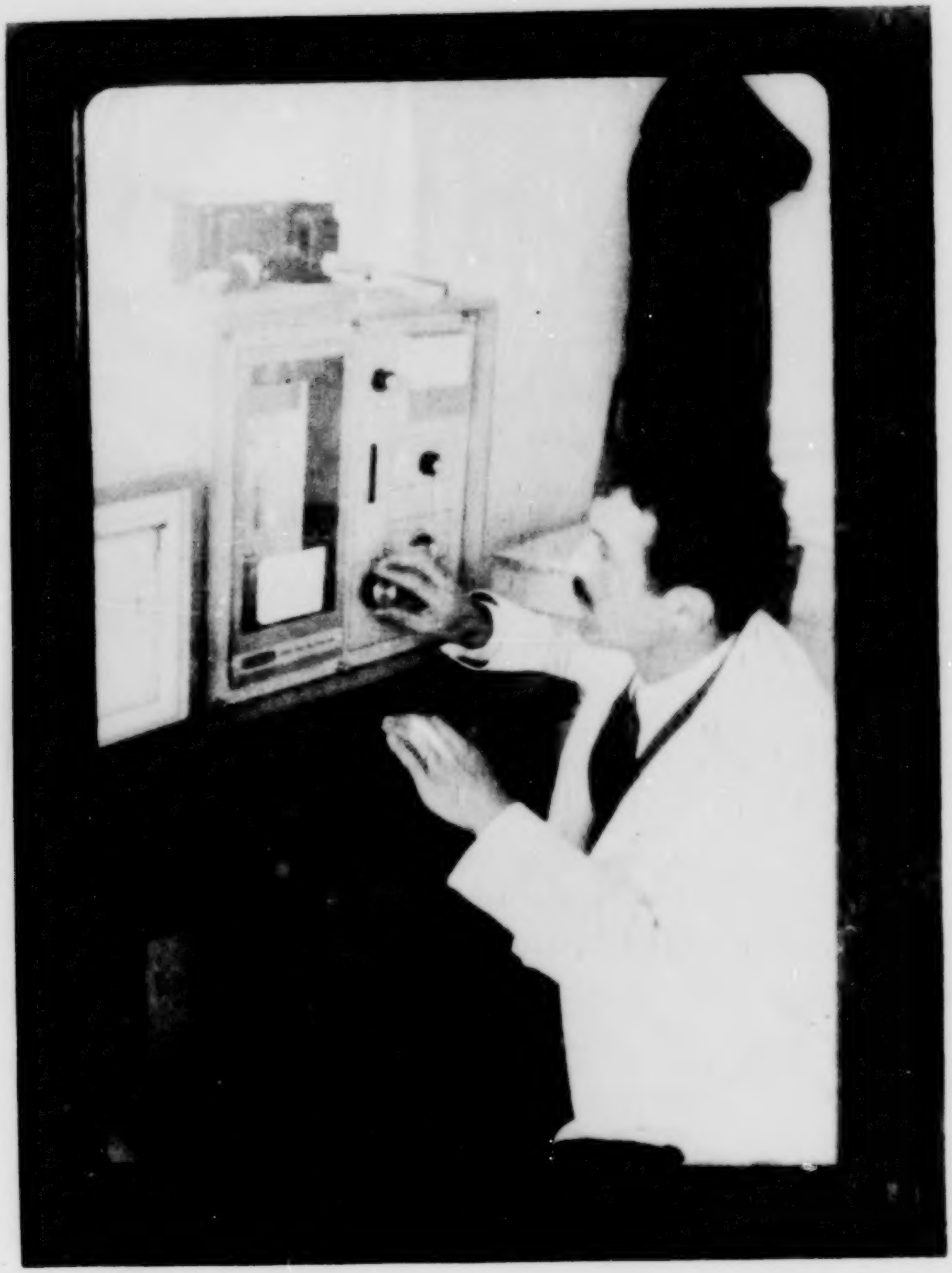


FIGURE A–15. CONTINUOUS COULOMETRIC ANALYZER FOR SULFUR DIOXIDE.

of total sulfur in the atmosphere. This instrument, shown in Figure A-16, is not yet field-proven and requires considerable attention from the operator.

A non-dispersive infrared (NDIR) analyzer was selected for monitoring carbon monoxide. This type of instrument has been adequately field tested and proven to be very reliable in the field requiring a minimum of maintenance. The particular monitoring device used incorporated the following features:

(1) Twice daily automatic calibration

(2) Correction for water vapor in air sample

To provide an initial measure of the hydrocarbon in the air of Ankara a total hydrocarbon analyzer utilizing the flame ionization method of detection was chosen. This instrument, although unable to identify the non-reactive portion of hydrocarbons, has been thoroughly field-proven over a number of years. In general, this instrument can provide a good indication of the level of hydrocarbons to be expected in the area.

The chemiluminescence analyzer was chosen for measurements of oxidant (ozone). The need for continuous data (1 hour averages) requires the use of an automatic sampler/analyzer. This method has been shown to be very specific to ozone and has been adequately field-tested.

Two separate systems were selected for measuring NO_2, a continuous coulometric NO_2 monitor and a fritted bubbler device designed for collecting 24-hour samples. The continuous monitor proved to have an interference from SO_2 and its use was discontinued early in the study.

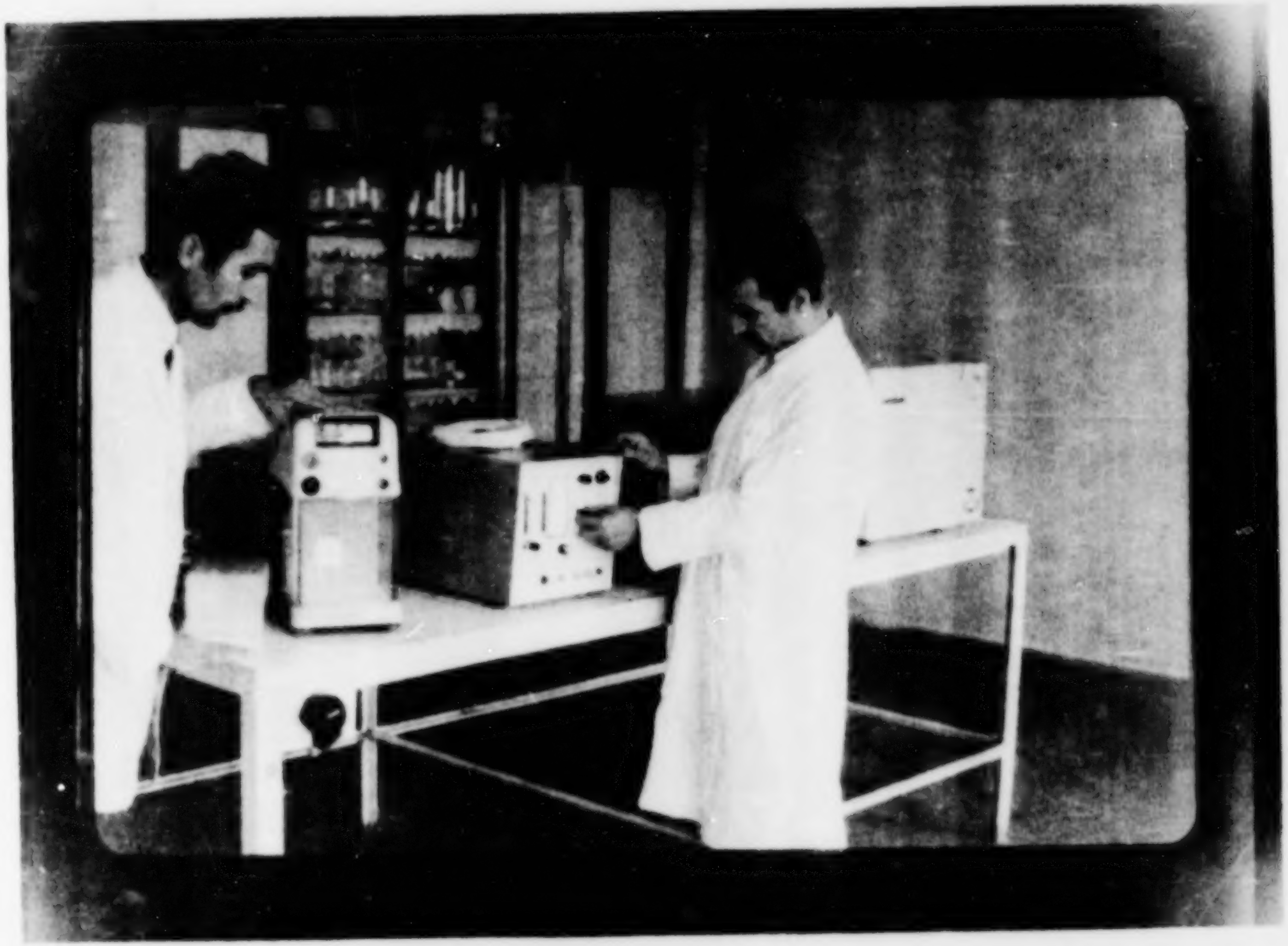


FIGURE A–16. FLAME PHOTOMETRIC INSTRUMENT FOR THE CONTINUOUS ANALYSIS OF TOTAL SULFUR.

The fritted bubbler device consists of a membrane-type pre-filter to remove particulate matter, a 50 ml polypropylene collection tube containing Jacobs-Hochheiser absorbing solution, an orifice for controlling flow rate, a dry meter for measuring air volume, and a vacuum pump. The samples were analyzed in the laboratory using a spectrophotometer.

B. Sampling Network. The monitoring network for Ankara was designed and installed in two stages. For sulfur oxides and particulates a multi-station network was necessary to characterize region-wide pollution. Because of the cost, the lack of adequate models, and not as severe problem as that for SO_2 and particulates, for the primarily motor vehicle generated pollutants, it was decided to only obtain preliminary measurements of these pollutants, i.e., monitoring was limited to a single site.

Designers of the study prescribed a network of 13 stations for SO_2 and particulates, located according to Figure A-17 to adequately delineate the pollution levels and their variability in Ankara. This determination, based on judgment and experience, was derived from considerations of earlier air quality data, size of the area, distribution of population, location of sources, topography, and meteorology. As shown in Figure A-17 and described in Table A-10, the stations were located in areas of different types of activities, ranging from an entirely rural area (Esenboga) to residential and industrial sectors. The majority of the stations were situated near the center of the city, where pollutant concentrations were thought to be highest. It must be

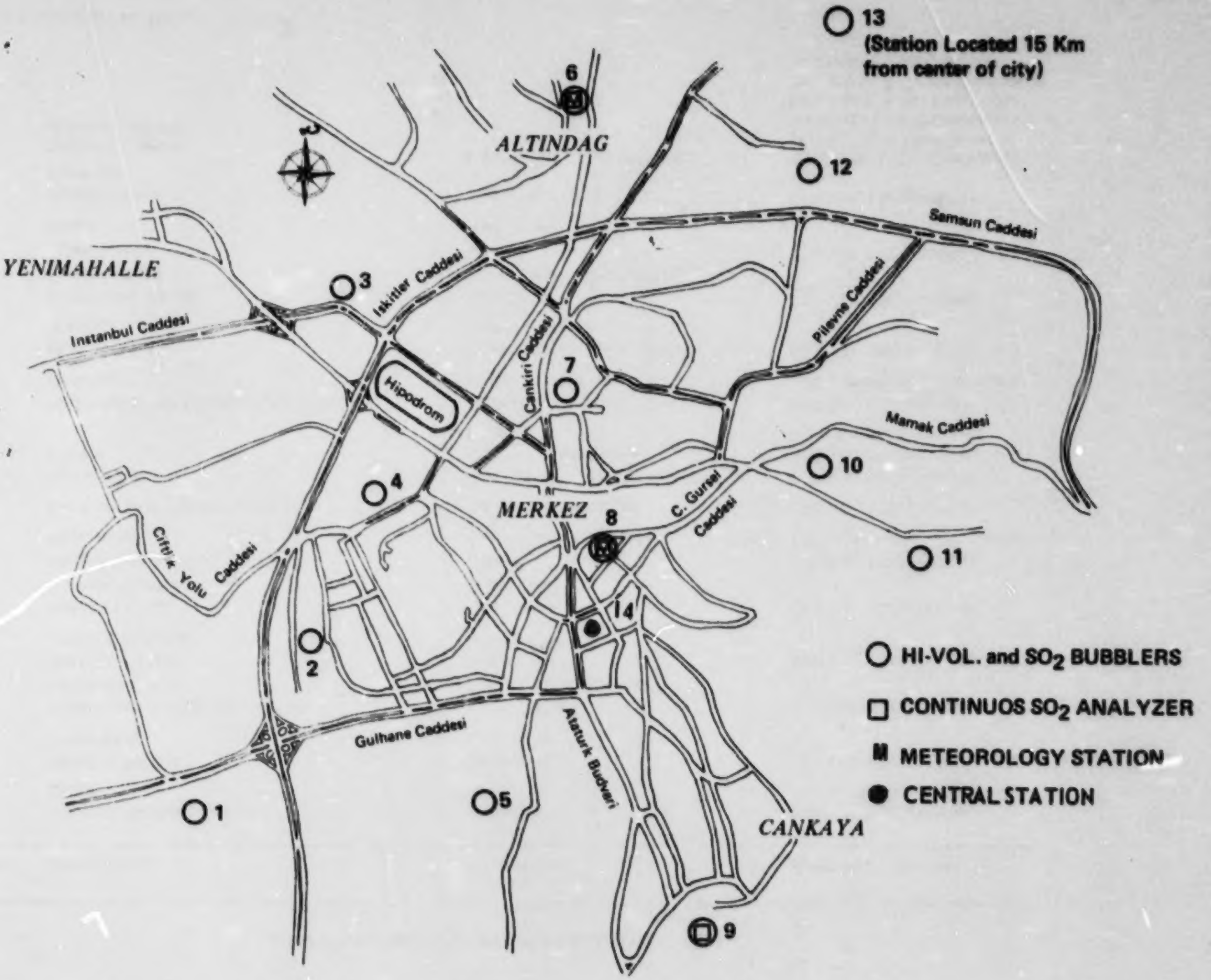

13
(Station Located 15 Km from center of city)
6
ALTINDAG
12
YENIMAHALLE
3
Iskitler Caddesi
Samsun Caddesi
Instanbul Caddesi
Pilevne Caddesi
7
Hipodrom
Cankiri Caddesi
Mamak Caddesi
10
4
MERKEZ
8
C. Gursel Caddesi
11
Ciftlik Yolu Caddesi
14
2
Gulhane Caddesi
Ataturk Budvari
1
5
CANKAYA
9
○ HI-VOL. and SO2 BUBBLERS
□ CONTINUOS SO2 ANALYZER
M METEOROLOGY STATION
● CENTRAL STATION

FIGURE A-17. Location of Monitoring Stations in Ankara.

TABLE A-10

LOCATION AND DESCRIPTION OF SAMPLING SITE

Site No.	Site Location	Type of Site	Sampling Equipment
1.	Mining & Mineral Institute, Balgat	Suburban	1 Hi-Vol, 1 SO_2 bubbler
2.	Republic School, Bahcelievler	Residential – apartments	1 Hi-Vol, 1 SO_2 bubbler
3.	Government Construction Office, Varlik Mahallesi	Light industrial – fuel storage, coal – wood	1 Hi-Vol, 1 SO_2 bubbler
4.	Technical School, Anittepe Mahallesi	Residential – apartments	1 Hi-Vol, 1 SO_2 bubbler
5.	Military College, Vorganci Mahallesi	Commercial – office buildings	1 Hi-Vol, 1 SO_2 bubbler
6.	Meteorological Office, Mebusevleri	Suburban – single - unit - residences	1 Hi-Vol, 1 SO_2 bubbler, 1 SO_2 continuous instrument
7.	Governor of Ankara Province, Ulus	Commercial & Offices	1 Hi-Vol, 1 SO_2 bubbler
8.	Hygiene School, Sihhiye	Commercial – Residential school – apartments – hospital	1 Hi-Vol, 1 SO_2 bubbler 1 SO_2 continuous instrument 1 Total sulfur instrument
9.	Residence of the President of Turkey, Cankaya	Residential – single unit residence	1 Hi-Vol, 1 SO_2 bubbler 1 SO_2 continuous instrument
10.	Medical School, Dikimevi,	Commercial – Residential school – offices	1 Hi-Vol, 1 SO_2 bubbler
11.	Elementary School, Samanlik Baglari	Residential – low – income single units	1 Hi-Vol, 1 SO_2 bubbler
12.	Police Station Siteler	Commercial – lumber industry	1 Hi-Vol, 1 SO_2 bubbler
13.	Research Farm Esenboga	Nonurban / rural	1 Hi-Vol, 1 SO_2 bubbler
14.*	Research Council of Turkey (TBTAK)	Commercial-Office Buildings	1 Hi–Vol, 1 SO_2 Continuous Instrument, 1 Total Sulfur Instrument, 1 CO Continuous Instrument, 1 HC Continuous Instrument, 1 Ozone Continuous Instrument, 1 NO_2 Bubbler

*Site 8 moved in Fall 1971.

remembered that the initial network was only comprised of samplers for SO_2 and particulates.

Sites were selected by considering the availability of adequate housing for equipment and personnel, representativeness of the location, accessibility, and security. The following guidelines were observed:

- All samplers were located at street or second-floor levels, i.e., between 2 and 6 meters above ground.

- All samplers were located at least 100 meters from any known source of pollution, such as smokestacks or chimneys.

- The intake probes for SO_2 and NO_2 samplers and SO_2 sampler-analyzers were placed at least 1 meter from the walls of structures.

- The inlet probes for the CO, ozone, and hydrocarbon instruments were located approximately 4 meters above the ground.

The monitoring site for CO, hydrocarbons, oxidants, and nitrogen oxides was chosen in the area where the emissions of these pollutants are one of the highest, i.e., in a heavily traveled area near the center of Ankara. The instrumentation was housed in a laboratory at the Scientific and Technical Research Council of Turkey (TBTAK).

After the completion of the first phase, it was necessary to relocate two of the stations. The central station, including the support laboratory, was moved from the Hygiene School (#8) to TBTAK. The sampling station at the Military College was relocated in the same vicinity.

C. Sampling Period and Frequencies. For the initial assessment phase (SO_2 and TSP) the 13 station network was operated from October 1, 1970, to March 31, 1971. For Phase II pollutants the primary assessment phase was conducted from October 1, 1971, to March 31, 1972. The entire monitoring network was continued past these periods.

Integrated samplers (SO_2 and NO_2 bubblers and Hi-Vols) were operated every day, and collecting media were changed daily at 1400 hours. The continuous sampler-analyzers were operated continuously throughout the sampling period.

IV. Sampling Operation

A. Implementing the Monitoring Network. As described earlier, the general locations of the sampling sites were determined from earlier SO_2 and smokeshade measurements, data on population density, topographical maps, meteorological data, and traffic density. Air monitoring technicians visited these areas and selected within the area the building most suitable for housing the sampling equipment. Permission for use of the selected buildings was obtained from the appropriate individuals or agencies. At the same time, requests were made for the services of someone at each site who could operate the monitoring equipment.

The air monitoring equipment was assembled at the Meteorological Office (Mebusevleri) and preliminary operational checks of the instruments were made to insure that no damage had occurred during shipment. For ease of operation, "on-off" switches were added to the Hi-Vol samplers. The continuous monitoring instruments were assembled at the Hygiene School, where a chemical analytical laboratory was established.

Each of the continuous instruments was given a final calibration check and was operated at the Hygiene School laboratory for several days.

In the supporting laboratory, established at the Hygiene School (later moved to TBTAK) a distillation-ion exchange apparatus was installed to provide high-quality water for operation of the coulometric analyzers and for use in the SO_2 impinger analysis. Standard SO_2 solutions were prepared, and West-Gaeke calibration curves were developed. Procedures were established for preparing and handling the absorbing solutions for the SO_2 impingers in the network; racks were procured for use in transporting the bubbler tubes from the field to the laboratory. The Hi-Vol filters, which had been weighed and numbered in the Cincinnati laboratory, were organized for distribution to the sampling stations.

After thorough check out and calibration, the monitoring equipment was installed at each site. Additional electrical circuitry and wiring was usually required to accommodate the equipment; similarly, installation of sampling probes for the SO_2 monitors necessitated some modification of the shelter areas. During installation, an effort was made to have the designated sampling operator assist with the work to give him working knowledge of the equipment. Operators were instructed in the use of data sheets designed for the study and were encouraged to contact the monitoring network manager concerning any apparent difficulties with the sampling equipment. Each operator used the monitoring equipment under standard operating conditions for several days before the station began contributing data to the study.

Implementation of the Phase I monitoring network from site selection through equipment installation and operator training began in mid-September and was completed by the end of October. Early in the monitoring program, several sites were relocated because of operational difficulties or newly established pollution sources nearby.

The implementation of the monitoring station for the monitoring station for the automobile-related pollutants required considerable time and effort in preparing the instrumentation for field use. Although the CO instrument installed in May 1971 did not perform properly during the first three months of operation, the generation of valid data began in Setpember 1971 and continued from that time to the present. The instrumentation for hydrocarbons, ozone, and nitrogen oxides was installed in the fall of 1971 and became operational October 1, 1971.

B. Operation of the Network. With some exceptions, the monitoring network was made operational in October 1970. Each of the mechanical stations, i.e., SO_2 bubblers and Hi-Vols, were serviced daily by the operator. This task, accomplished at 1400 hours, involved changing the Hi-Vol filters and the bubbler solution, and noting the air flow rate for each. The collected samples were taken to the Hygiene School laboratory on a daily basis. The Hi-Vol filters were packaged for shipment to the United States for weighing; the SO_2 impinger solutions were stored in a refrigerator for subsequent chemical analysis in the Hygiene School laboratory.

The continuous coulometric instruments were checked each day at 1200 hours to ensure that they were operating properly. Periodically, the strip charts were removed and sent to the EPA Cincinnati laboratory for validation and reduction of data. Unfortunately, the total sulfur analyzer failed several weeks after installation and was not operational for the remainder of the monitoring period.

Except for the total sulfur analyzer, all continuous analyzers operated well throughout the study, requiring only routine maintenance. Some problems were encountered with condensation of water vapor in the SO_2 impinger lines leading to the air meter, but these were partially overcome by adding a trap to the downstream collection tube. Several Hi-Vol sampler motors were damaged by overheating caused by the heavy particulate loadings on the filters. The availability of spare Hi-Vol samplers and motors limited down time to only a few days.

More difficulty was encountered in monitoring Phase II pollutants. As pointed out earlier, the continuous analyzer for NO_2 measurement, because of faulty design, was found to be inoperable at the very start of the program, thus the only data collected were the integrated 24-hour measurements. Once the initial difficulties with the CO analyzer were overcome, this instrument, although requiring considerable maintenance, has functioned reasonably well. This is also true for the ozone monitoring system. The total hydrocarbon instrument operated only for three months and had to be shut down when hydrocarbon-free air, used as a zero reference, could not be secured in Turkey. Since that time a catalytic system for generating hydrocarbon free air has become available. This again points out the importance of having readily-available supplies for the instruments.

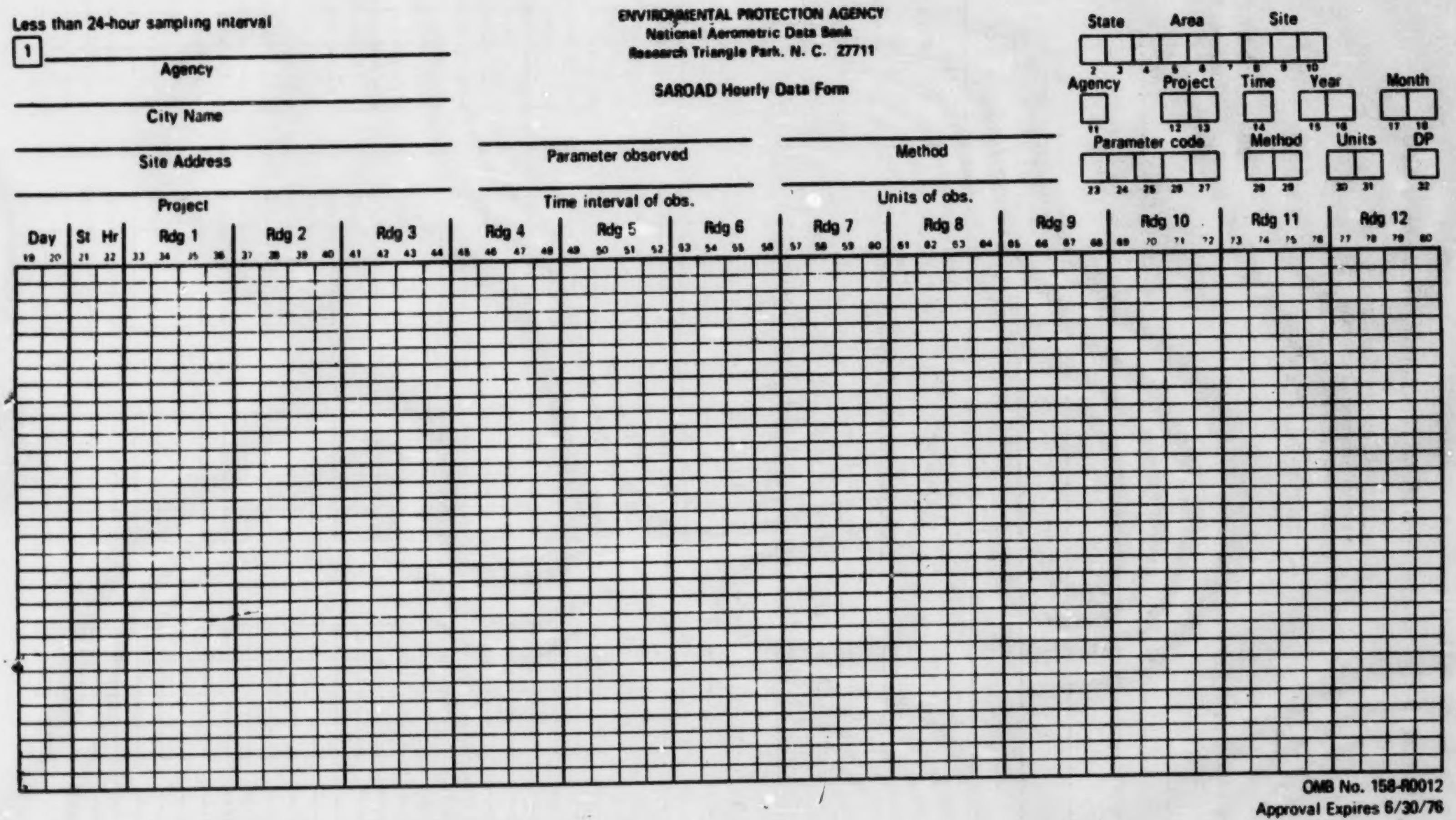
C. Data Validation and Reduction. Results of SO_2 impinger sampling network were routinely sent to the United States laboratories in Cincinnati, and later to North Carolina. Each measurement was examined; if errors were found in air volume readings or inconsistencies were observed in the chemical analytical results, the measurements were corrected or discarded. Similarly, the Hi-Vol data and strip-chart tracings from the continuous analyzers were individually examined and data were discarded upon evidence of instrument malfunction. The same procedure was followed for Phase II pollutants.

Following the validation procedure, the data were hand-recorded on SAROAD forms and subsequently entered on punch cards for computer processing. So that the continuous SO_2 data could be handled easily, the strip chart information was reduced to hourly average concentrations; (Fig. A-18), the Hi-Vol and SO_2 and NO_2 impinger data were reported as 24-hour averages (Fig. A-19). The punch cards were computer processed for use in the air quality model and for derivation of appropriate air quality assessment relationships.

V. Results

As pointed out earlier the air quality information available from the Ankara study consists of three sets of data. The first set includes SO_2 and TSP data collected during the first phase of the study. These data, described in the earlier draft of the guidelines and repeated here, were used to validate the diffusion model and provide the initial appraisal of the pollution problem in Ankara. The second set of data consists of the SO_2 and TSP measurements made since the end of Phase I of the study, e.g., April 1, 1971, to March 31, 1972. These data provide

FIGURE A-18. Recording Form for Continuous SO_2 Data.



Less than 24-hour sampling interval

☐1 Agency

City Name

Site Address

Project

ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
Research Triangle Park, N. C. 27711

SAROAD Hourly Data Form

Parameter observed

Time interval of obs.

Method

Units of obs.

State ☐☐ (2–3) Area ☐☐☐☐ (4–7) Site ☐☐☐ (8–10)

Agency ☐ (11) Project ☐☐ (12–13) Time ☐ (14) Year ☐☐ (15–16) Month ☐☐ (17–18)

Parameter code ☐☐☐☐☐ (23–27) Method ☐☐ (28–29) Units ☐☐ (30–31) DP ☐ (32)

Day	St	Hr	Rdg 1	Rdg 2	Rdg 3	Rdg 4	Rdg 5	Rdg 6	Rdg 7	Rdg 8	Rdg 9	Rdg 10	Rdg 11	Rdg 12
19 20	21	22	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55 56	57 58 59 60	61 62 63 64	65 66 67 68	69 70 71 72	73 74 75 76	77 78 79 80

OMB No. 158-R0012
Approval Expires 6/30/76

FIGURE A–19. Recording Form for 24 - hour Average Concentrations of SO_2.

ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
Research Triangle Park, N. C. 27711

SAROAD Daily Data Form

OMB No. 158-R0012
Approval expires 6/30/76

24-hour or greater sampling interval

2
1

Agency ____________________

City Name ____________________

Site Address ____________________

Project ____________________ Time Interval ____________________

State		Area			Site			
☐	☐	☐	☐	☐	☐	☐	☐	☐
2	3	4	5	6	7	8	9	10

Agency	Project	Time	Year	Month
☐	☐☐	☐	☐☐	☐☐
11	12 13	14	15 16	17 18

Name PARAMETER Code	Name PARAMETER Code	Name PARAMETER Code	Name PARAMETER Code
☐☐☐☐☐	☐☐☐☐☐	☐☐☐☐☐	☐☐☐☐☐
23 24 25 26 27	37 38 39 40 41	51 52 53 54 55	65 66 67 68 69
Method ☐☐ 28 29 Units ☐☐ 30 31 DP ☐ 32	Method ☐☐ 42 43 Units ☐☐ 44 45 DP ☐ 46	Method ☐☐ 56 57 Units ☐☐ 58 59 DP ☐ 60	Method ☐☐ 70 71 Units ☐☐ 72 73 DP ☐ 74

Day 19 20	St 21	Hr 22	33 34 35 36	47 48 49 50	61 62 63 64	75 76 77 78
0 1						
0 2						
0 3						
0 4						
0 5						
0 6						
0 7						
0 8						
0 9						
1 0						
1 1						
1 2						
1 3						
1 4						
1 5						
1 6						
1 7						
1 8						
1 9						
2 0						
2 1						
2 2						
2 3						
2 4						
2 5						
2 6						
2 7						
2 8						
2 9						
3 0						
3 1						
DP →			4 3 2 1 0	4 3 2 0	4 3 2 1 0	4 3 2 1 0

additional information on the ambient levels of these pollutants especially as they pertain to their seasonal variability and annual average. A comparison of two successive winter seasons could also be made. The third set includes initial information on the atmospheric concentrations of carbon monoxide, hydrocarbons, oxides of nitrogen and oxidants (ozone). The information is limited since measurements were made at only one station and currently available data represent only six months of monitoring. Each of these sets are summarized in the following sub-sections.

A. Initial Assessment of SO_2 and TSP. The initial monitoring of these pollutants was conducted from October 1, 1970, to March 31, 1971. The data were analyzed to determine severity of pollution and the geographical and temporal variability in concentrations.

As shown in Table A-11, the 6-month average concentrations of suspended particulates ranged from 46 ug/m^3 at Esenboga (background station), approximately 15 km from the core of the city to 370 ug/m^3, in the heavily populated Ulus district in Ankara. The highest average concentration of sulfur dioxide, 307 ug/m^3, occurred in Bahcelievler; the lowest average, of 28 ug/m^3, again was recorded in Esenboga. In general, concentrations of both pollutants followed the same pattern; locations with high concentrations of suspended particulates also exhibited high concentrations of SO_2. This is not surprising, since the predominant sources in Ankara are common to both pollutants. A notable exception is Siteler, Station 12, where the observed high levels of suspended particulates are accompanied by relatively low SO_2 concentrations. The presence in this area of woodworking industry, a source of particulates but not of SO_2, may account for this deviation.

TABLE A-11

TOTAL SUSPENDED PARTICULATE AND SULFUR DIOXIDE AVERAGE CONCENTRATIONS IN ANKARA
OCTOBER 1970 - MARCH 1971

	Total Suspended Particulate (ug/m^3)			Sulfur Dioxide (ug/m^3)		
Station Number	Avg.	Max.	Min.	Avg.	Max.	Min.
1	109	421	12	94	474	5
2	311	508	37	307	1637	17
3	162	370	31	89	534	11
4	182	473	31	195	949	31
5	144	414	25	193	942	11
6	109	300	29	114	513	15
7	370	1013	49	275	940	10
8	229	598	85	280	987	52
9	71	212	13	113	465	6
10	212	451	69	221	635	29
11	185	483	48	172	925	13
12	290	748	22	92	497	7
13	46	165	6	28	134	0

In general, the average concentrations are highest in the center of the city, decreasing with distance outward in the direction of prevailing winds. The concentrations observed in Cankaya and Mebusevleri, for example, are about one-third of those observed in the central portion of Ankara. Figures A-20 and A-21 present the average concentrations of suspended particulates and SO_2, respectively, in terms of geographic location within the study area.

Since air quality standards have not been set in Turkey, the severity of pollution in Ankara may be illustrated by comparing the observed levels with the ambient air quality standards established for the United States. For suspended particulate matter, the primary standards call for an annual average concentration of 75 ug/m^3; the maximum 24-hour concentration, not to be exceeded more than once per year, is 260 ug/m^3. For SO_2, the standards cite an annual average concentration of 80 ug/m^3 and a maximum 24-hour concentration of 365 ug/m^3, not to be exceeded more than once per year. The measurement methods specified in the standards are identical with those used in the Ankara study.

Limited data did not allow camparison of annual averages after the first 6 months of the study and only the maximum values could be compared meaningfully. The percent of days that the U.S. standards were exceeded at each of the sampling sites is indicated in Fig. A-22. The U.S. suspended particulate standard was exceeded at all except the Esenboga sampling station. At seven of the stations, the standard was exceeded at least 20% of the time. At two of the stations, Ulus and Siteler, the measured were continually so high that they exceeded the standards 75% and 55% of the time, respectively. In SO_2 measurements, the United States 24-hour standard

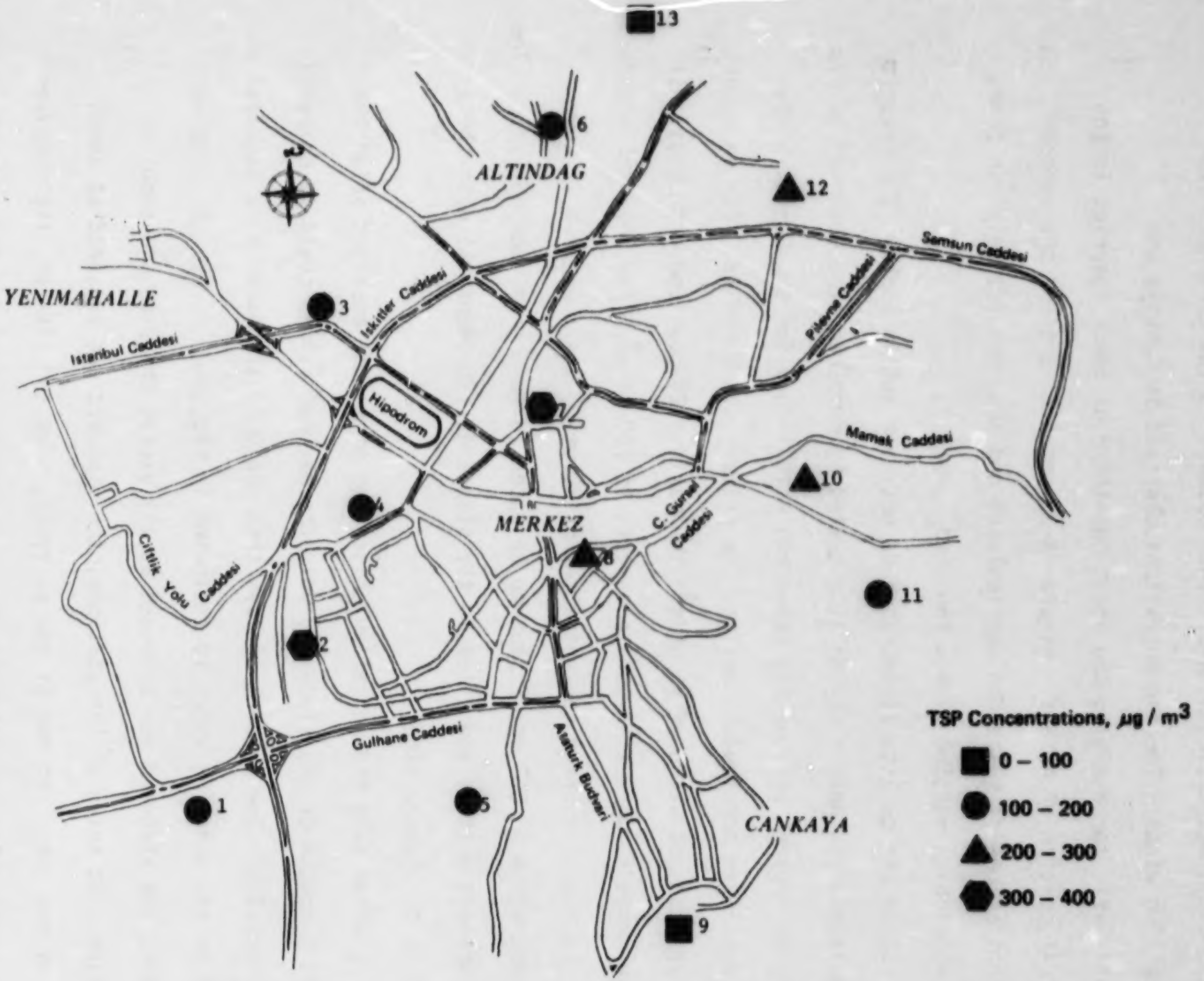

13
6
ALTINDAG
12
YENIMAHALLE
3
Iskitler Caddesi
Semsun Caddesi
Istanbul Caddesi
Pilevne Caddesi
Hipodrom
7
Mamak Caddesi
10
4
MERKEZ
C. Gursel Caddesi
8
Ciftlik Yolu Caddesi
11
2
Gulhane Caddesi
Ataturk Budvari
1
5
CANKAYA
9
TSP Concentrations, μg / m³
■ 0 – 100
● 100 – 200
▲ 200 – 300
⬢ 300 – 400

FIGURE A–20. Total Suspended Particulates Concentrations, Ankara, October 1970 – March 1971.

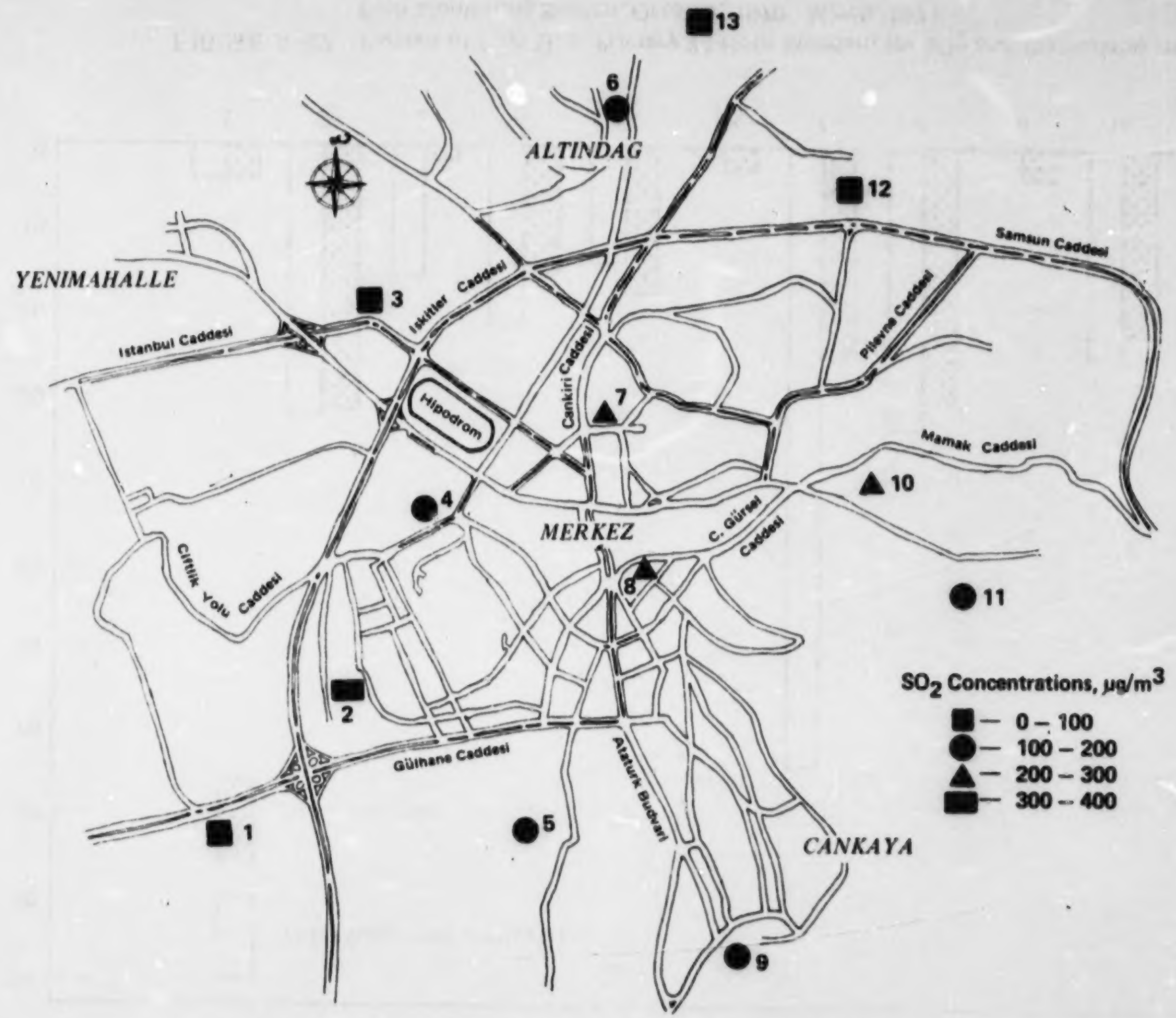

13
6
ALTINDAG
12
YENIMAHALLE
3
Iskitler Caddesi
Samsun Caddesi
Pilevne Caddesi
Istanbul Caddesi
Cankiri Caddesi
7
Hipodrom
Mamak Caddesi
10
4
MERKEZ
C. Gürsel Caddesi
8
11
Ciftlik Yolu Caddesi
2
Gülhane Caddesi
Ataturk Budvari
1
5
CANKAYA
9
SO_2 Concentrations, µg/m^3
■ — 0 – 100
● — 100 – 200
▲ — 200 – 300
▬ — 300 – 400

FIGURE A–21. SO_2 Concentrations, Ankara, October, 1970 – March, 1971.

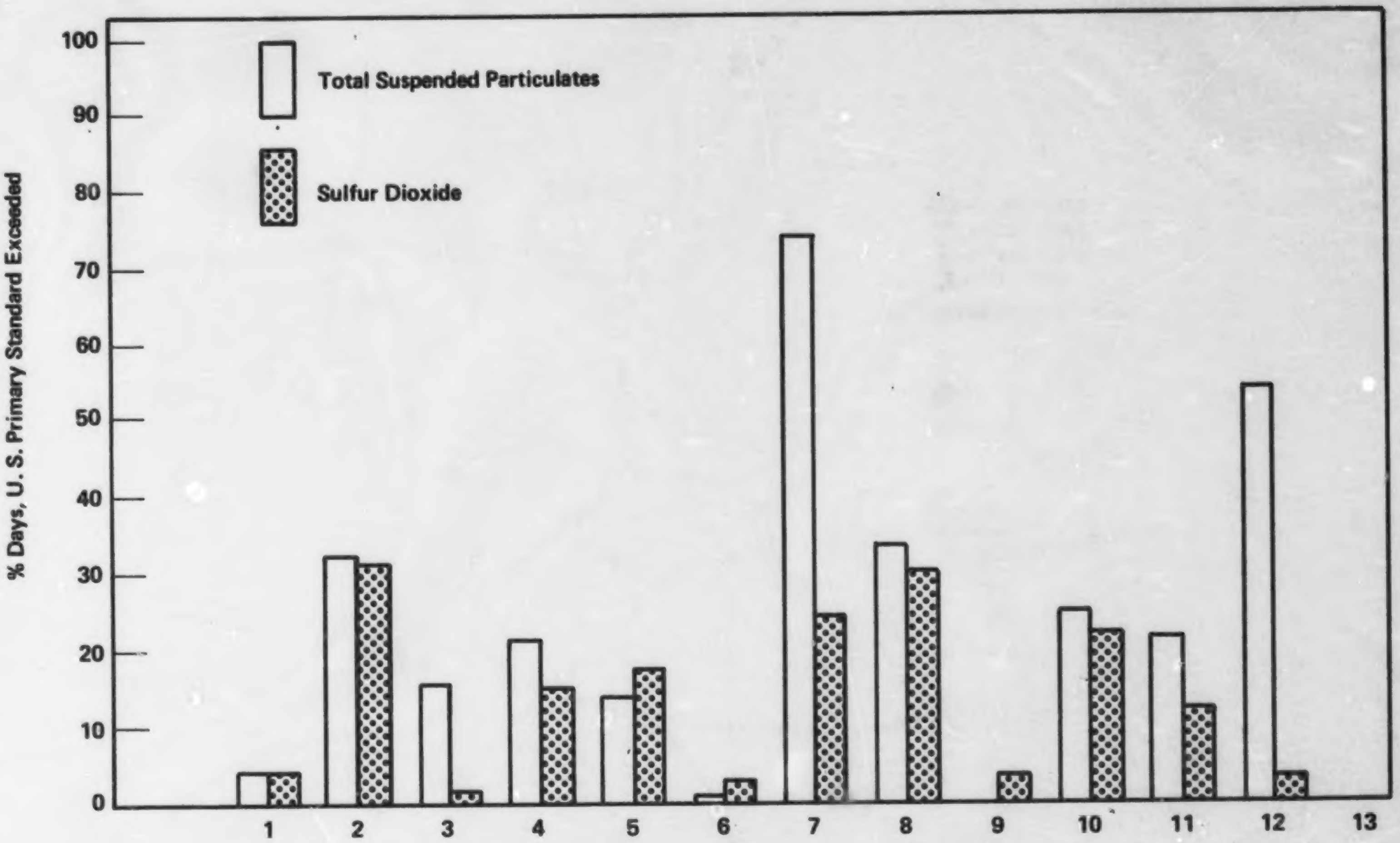


FIGURE A–22. Percent of Days U. S. Primary 24-Hour Standard for SO_2 and Particulates was Exceeded at Each Monitoring Station, October, 1970 - March, 1971.

was exceeded at 11 of the 13 sites; concentrations were highest at Bahcelievler and Sihhiye, the standards being exceeded about 40% of the time.

Since space heating of buildings is the major source of both SO_2 and particulate matter, ambient air concentrations of these pollutants should be strongly influenced by the ambient temperature. Although only six months data were available at the end of the first phase, a strong seasonal effect is evident, especially with SO_2. At all stations the levels increased to a maximum in December or January and then reapidly decreased as fuels were used less for space heating purposes. Figure A-23 shows the combined monthly average for all of the stations. Note that the average December concentration is almost three times the average for March.

Although suspended particulate concentrations show some seasonal influence, it is not as pronounced. Also, the combined average shows that concentrations during March, 1971 are higher than those during February, 1971. Increased winds during March may cause windblown particulate and added reentrainment. That the seasonal influences is less marked can be attributed to a combination of factors: higher background concentrations, less seasonally distributed emissions, reentrainment of dust, and the amount of precipitation.

The day-to-day variability of concentrations is illustrated in Figure A-24 which presents the six months of data for both pollutants for Station #7, Ulus. Although drastic variability is apparent, the tendency is for levels to build and remain high for a number of days. For example, the suspended particulate concentration rose from 170 ug/m^3 on December 31 to 700 ug/m^3 on January 1 and remained above 650 ug/m^3 for five consecutive days, with peaks of slightly over 1000 ug/m^3.

The three continuous, automatic sampler-analyzers were operated

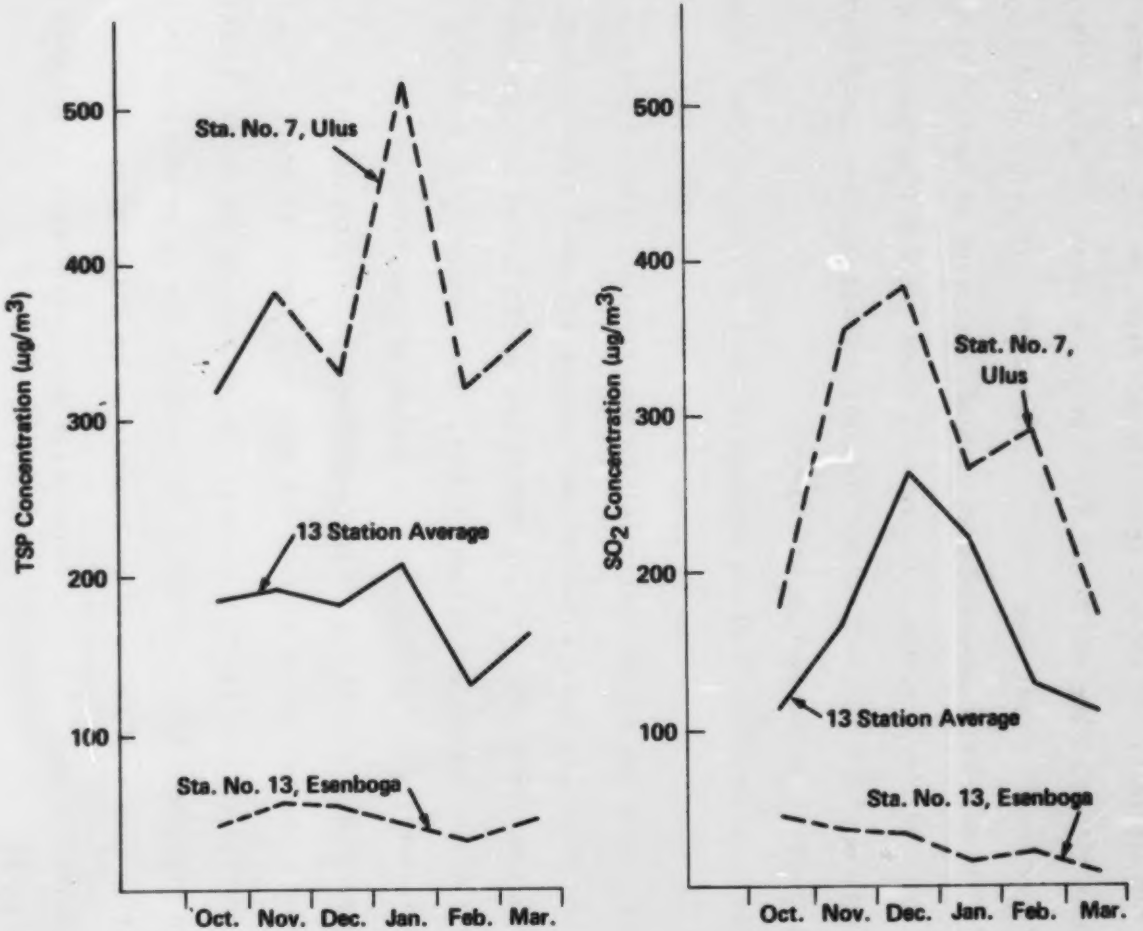


FIGURE A–23. Monthly Variation in Concentrations of SO_2 and TSP (Oct.-Mar.) Network Composite, Highest Station (Ulus) and Lowest Station (Esenboga).

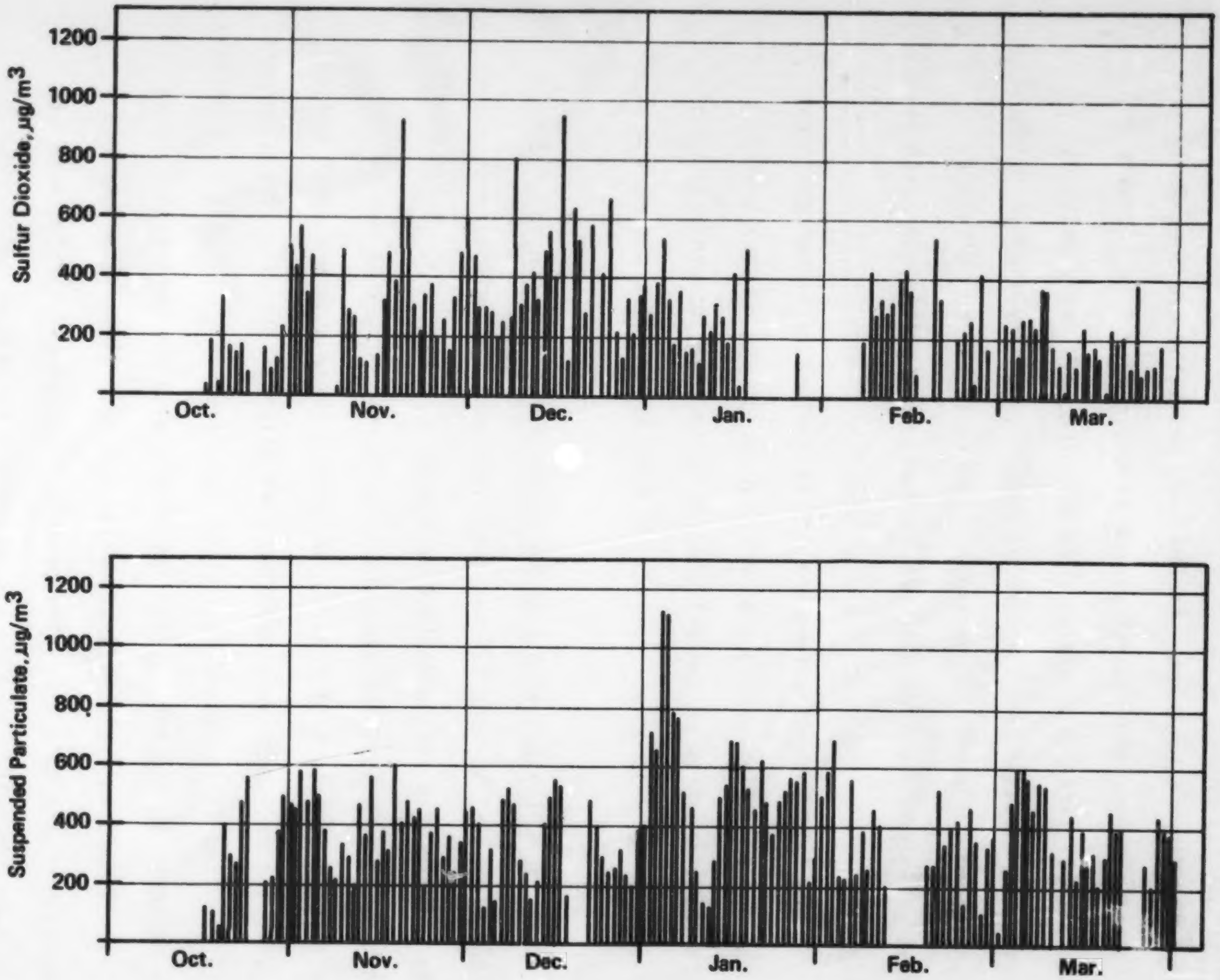


FIGURE A–24. Daily Concentrations of SO_2 and Suspended Particulate at Station No. 7, Ulus.

to determine the hour-to-hour variability in SO_2 concentrations and to observe any diurnal patterns. Figure A-25 shows the average hourly concentrations over the 3-month period from December 1 to February 28. Curves for all three stations show roughly the same daily pattern; highest concentrations in the morning, and a secondary miximum in the early evening. The diurnal pattern of SO_2 reflects the influence of inversions and the irregular hourly fuel consumption rate, with peaks during the morning and evening mealtimes.

Figure A-26 shows the frequency distributions of 3-hour averages for the three continuous SO_2 stations. At both, the Hygiene School and Cankaya, the peak concentrations are quite high; concentrations of almost 1000 ug/m^3 occur at least two percent of the time during the winter season.

B. Sulfur Dioxide and Suspended Particulates - 18 months of Data. The monitoring of SO_2 and TSP was continued past the initial assessment phase. These data are summarized in Tables A-12 and A-13. It is important to note that two stations were moved during this period resulting in some loss of continuity. Also, the conditions under which the sampling equipment were operated (variations in input voltage, current, etc.) resulted in increased instrument downtime with attendant loss of data.

As shown in the tables, the levels of pollution during the winter of 1971-72 were much higher that during the initial sampling period. Comparison of the data for these periods shows an average increase of 42 percent for sulfur dioxide and 30 percent for suspended particulate. (The comparison was made on basis of only the stations reporting data for both periods). In both cases, notable increases were recorded

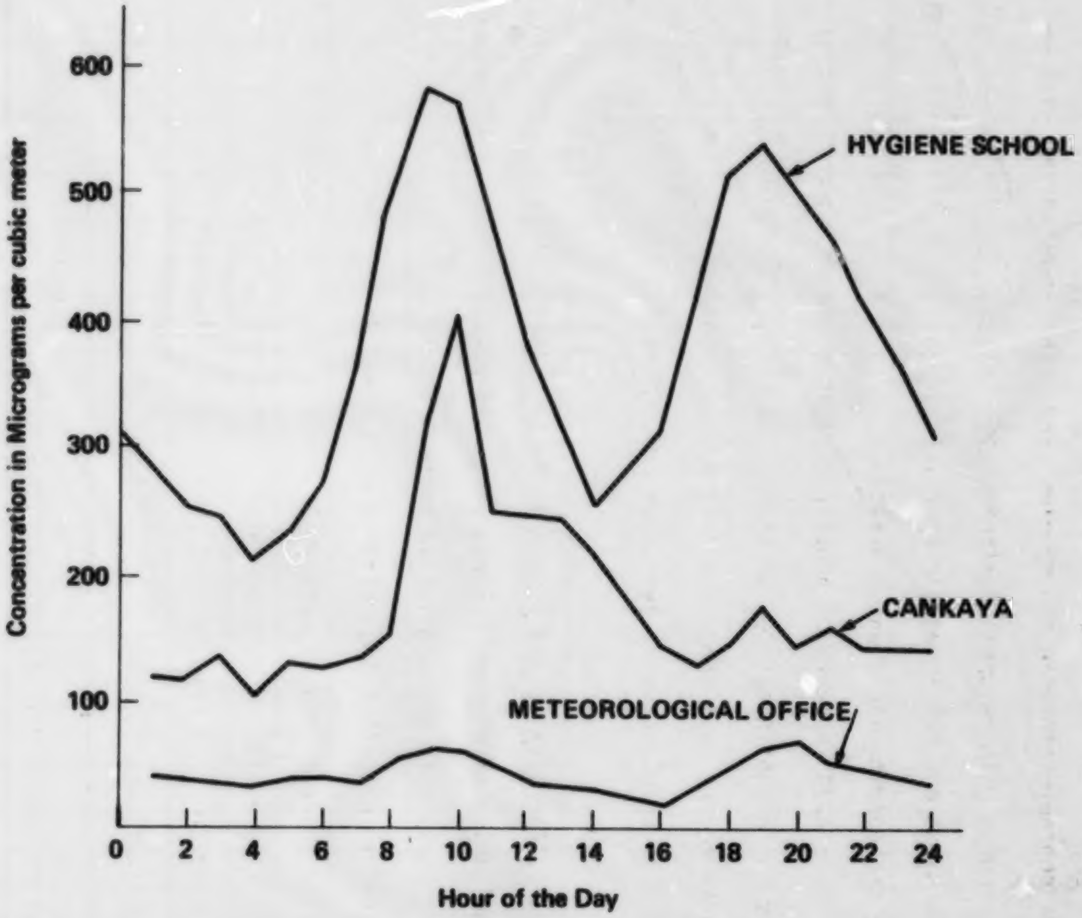


FIGURE A–25. Variation in Hourly SO_2 Concentrations - 3 month average (Dec.-Feb.).

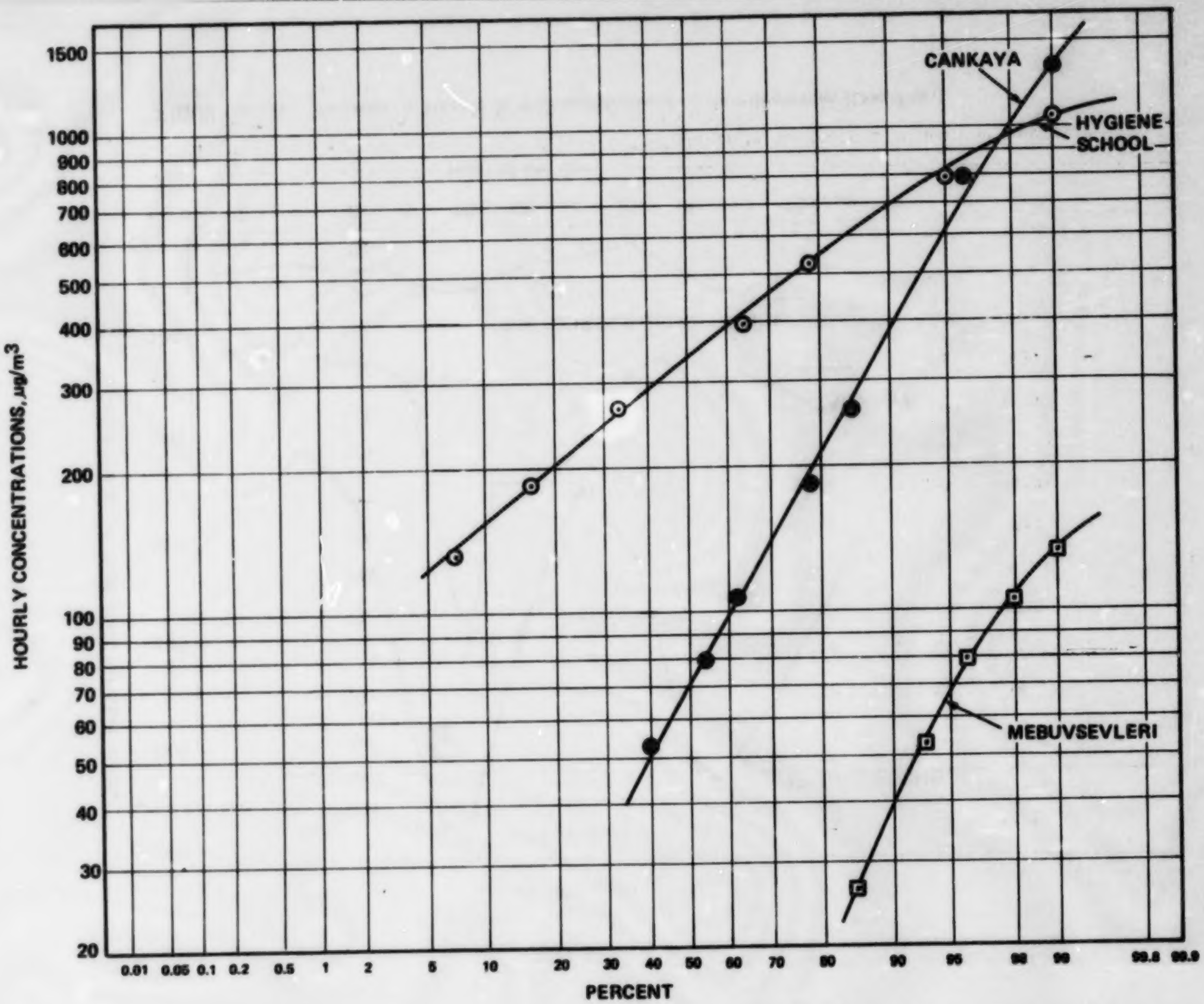


FIGURE A-26. Frequency Distribution of 3 Hour Concentrations, Dec. - Feb.

TABLE A–12

SULFUR DIOXIDE AVERAGE CONCENTRATIONS IN ANKARA (ug/m^3)

October 1970 – March 1972

Station Number	6–Month Averages			1971		
	Oct. '70 – Mar. – '71	Apr. '71 – Sept. '71	Oct. '71 – Mar. '72	Avg.	Max.	Min.[c]
1	94	–	–	–	–	–
2	307	17	338	133	1510	–
3	89	9	196	37	378	–
4	195	17	–	–	949	–
5[a]	193	–	–	–	–	–
6	114	8	140	56	513	–
7	275	30	516	180	412	–
8[b]	280	–	–	–	–	–
9	113	13	219	73	1120	–
10	221	39	343	109	1090	–
11	172	11	230	83	1160	–
12	92	–	–	–	–	–
13	28	5	–	–	–	–
14[a]	–	12	656	–	–	–

[a] Station relocated on block during second quarter of 1972. Data at station 14 too sparce to calculate averages.

[b] Central station relocated to TBTAK offices during third quarter of 1972.

[c] Below minimum detectable limit of 25 ug/m3.

TABLE A–13

TOTAL SUSPENDED PARTICULATE AVERAGE CONCENTRATIONS IN ANKARA (ug/m^3)

October 1970 – March 1972

Station Number	6–Month Averages			1971		
	Oct. '70 – Mar. '71	Apr. '71 Sept. '71	Oct. '71 – Mar. '72	Avg.	Max.	Min.
1	109	117	195	132	746	24
2	215	166	225	176	467	24
3	162	119	223	155	604	26
4	182	138	211	174	665	47
5[a]	144	–	–	–	–	–
6	109	75	116	86	300	25
7	370	312	426	372	1013	83
8[b]	229	–	–	–	–	–
9	71	96	146	93	369	13
10	212	255	305	268	545	38
11	185	405	–	208	556	46
12	290	–	–	–	–	–
13[a]	46	52	79	46	159	17
14[a]	–	187	313	–	–	–

[a] Station relocated one block during second quarter of 1972. Data at station 14 too sparce to calculate averages.

[b] Central station relocated to TBTAK offices during third quarter of 1972

for all of the sampling sites. The primary reason for these increases was the substantially colder winter experienced in 1971-72 which required more fuel to be consumed and unfavorable meteorological conditons. The average temperature for the six month sampling period in 1970-71 was 5.5° C as compared to 4.2° C during the following winter.

The availability of data for two successive winters illustrates the extreme variability in pollution levels in Ankara from one year to the next. The formulation of control strategies and particularly the calculation of emission reductions required must take into consideration the impact that the varying meteorological conditons can have on ambient levels of pollution.

A comparison of the air quality data for the winter seasons (October-March) with data for the summer (April-September) shows a slight summer decrease for suspended particulates and almost a total absence of SO_2 throughout Ankara during the summer. The average winter (1970-1971) concentration of 164 ug/m^3 decreased to 148 ug/m^3 during the summer. In the case of SO_2, the average winter level of 199 ug/m^3 decreased to below 25 ug/m^3, whigh is the detectability limit, In fact, only two stations showed average six-month concentrations above this limit, i.e., 30 and 39 ug/m^3. The reason for this is evident, during the summer season very little fuel is burned resulting in minimal SO_2 emissions. This is not the case for suspended particulates where a number of categories are responsible for the emissions. These, besides fuel burning, include industrial processes, construction, and wind-blown dust.

The annual average concentrations of both, SO_2 and TSP, are much higher than the allowable concentrations specified by the ambient air quality standards established for the United States. In case of suspended particulates in the U.S. standard of 75 ug/m^3 is exceeded at all locations except the background stations and for more than half of the locations the average concentrations are at least twice the U.S. standard. For sulfur dioxide, the U.S. average standard of 80 ug/m^3 is exceeded at only three locations for which yearly data were available. The extremely low summertime levels account for the relatively low annual averages.

C. Phase II Pollutants. The initial air quality data for the primarily automotive generated pollutants consist of six months of record at a single site for carbon monoxide and ozone, three months of date for hydrocarbons and nine months of data for oxides of nitrogen. These data, summarized in Table A-14 can, at best, provide only a preliminary overview of the magnitude of the problem for these pollutants. A single site, no matter how carefully and judiciously chosen, does not provide a sufficient basis for a comprehensive appraisal or assessment. Also, the periods record three, six and nine months; not sufficient to adequately describe the temporal nature of ambient concentrations. Furthermore, in the case of nitrogen dioxide, the measurement method employed (Jacobs-Hochheiser) has been recently found to be subject to considerable variability and error (see Guidelines). All these data, therefore, should be viewed with these constraints in mind. However, they should serve to provide an indication of the general severity of the "motor vehicle pollution" in Ankara.

Measurement of carbon monoxide indicate that on occasion, concentrations are high enough to exceed the levels that have been designated as ambient standards in the United States. Although the 1-hour maximum standard of

TABLE A–14. Carbon Monoxide, Total Hydrocarbons, Ozone and Nitrogen Dioxide Concentrations in Ankara 1971–1972 (ug/m^3)$_1$

POLLUTANT	AVERING TIME	PERIOD OF RECORD	PERCENTILES 10	30	50	70	90	95	99	MAXIMUM OBSERVATION	ARITHMETIC AVERAGE
CARBON MONOXIDE	8 hr.	OCT.–DEC. 1971	2,600	4,600	6,000	8,100	12,100	15,000	24,200	51,800	7,100
		JAN.–MAR. 1972	2,600	5,200	7,500	10,300	15,500	17,300	23,000	40,200	—
		OCT.–DEC. 1971	3,500	5,100	6,600	8,200	11,000	a	a	30,200	7,100
		JAN.–FEB. 1972	4,700	6,400	8,200	10,100	13,100	a	a	20,700	8,500
TOTAL HYDRO CARBON	1 hr.	OCT.–DEC. 1971	980	1,200	1,400	1,600	2,400	2,800	4,200	7,900	1,600
OZONE	1 hr.	OCT.–DEC. 1971	b	b	b	16	26	32	49	160	12
		JAN.– MAR. 1972	b	b	b	b	24	32	43	120	a
NITROGEN DIOXIDE	24 hr	OCT.–DEC. 1971	75	95	117	140	177	202	259	259	112
		JAN.–MAR. 1972	103	151	178	225	289	316	356	356	191
		APR.–JUN. 1972	44	56	62	74	106	130	232	232	72

a. Not sufficient data to calculate average.
b. Below detectability limits.

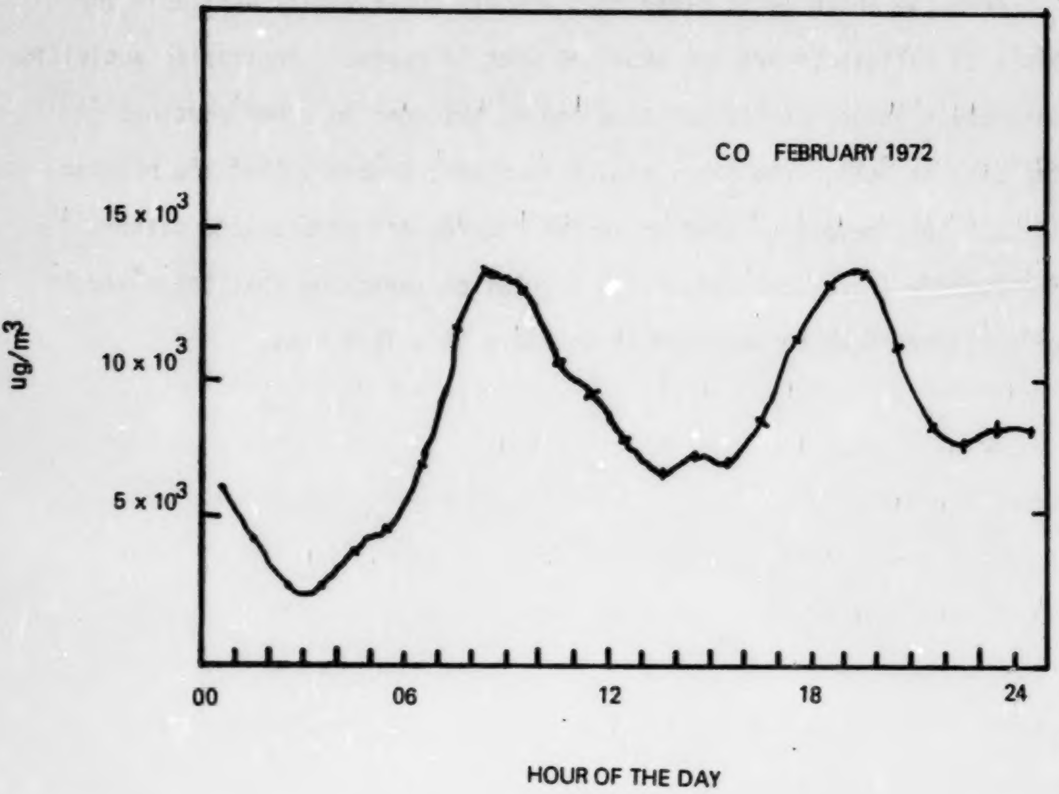
40,000 ug/m^3 is shown to be exceeded on few occasions, the 8-hour standard of 10,000 ug/m^3 is shown to be exceeded approximately 25% of the time. It must be remembered that these concentrations probably are not the highest to be found in Ankara. The station, although located in a major business area, is still some distance from a major thoroughfare. The extreme diurnal variability of CO is clearly illustrated in Figure A-27. The concentrations exhibit two distinct peaks conforming to rush hour periods, i.e., at 8 a.m. and 7 p.m. The average peak hour concentrations for February 1972 are nearly 14,000 ug/m^3.

For total hydrocarbons, only 3 months of data are available. The average during the period October-December 1971 was 1,800 ug/m^3, with a maximum hourly observation of 7,900 ug/m^3. It should be noted that a large fraction (more than 60%) has been shown in other cities to be naturally occurring methane, causing a suppression of hourly variability.

Measurements of ozone show that for at least the winter months (period of data) more than 50% of the time ambient levels were below the detectability limit of 10 ug/m^3. Only once during this period was the U. S. 1-hour standard of 160 ug/m^3 reached. Since sunlight is a factor in the formation of ozone, higher averages will occur during summer months, but this period was not covered by the data. Peak concentrations were noted to occur during the early afternoon, i.e., between noon and 2 p.m.

The collection efficiency of the method used in Ankara for measuring nitrogen oxides (Jacobs-Hochheiser) has been recently found to vary with ambient concentrations, and the values presented in Table A-14 may have to

FIGURE A–27. HOURLY VARIABILITY IN CO CONCENTRATIONS
(AVERAGE FOR FEBRUARY 1972)



be adjusted using a correction factor (now being developed). With this in mind, the data presented for oxides of nitrogen must be viewed with extreme caution. Until measurements of NO_2 are made with a more reliable method, or these data are corrected accordingly, very little can be said about NO_2 pollution levels in Ankara. The recorded concentrations do indicate, however, that the U. S. yearly standard of 100 ug/m^3 is probably exceeded in Ankara.

From the above it is clear that the air quality data available for Phase II pollutants are far short of what is needed. Monitoring activities must cover longer periods of time and be extended to other portions of the city as well. The early indications are, however, that the problem is much less severe as that of sulfur dioxide and particulate matter. The rapidly increasing automobile population indicates that these levels of pollutants can be expected to increase at a fast rate.

METEOROLOGICAL MEASUREMENTS

I. Introduction

Two sets of meteorological data were collected and used in this study. The basic inputs into the model were average values developed from meteorological measurements taken during the five years from 1964 through 1968. Information on wind flows, atmospheric stability, and other diffusion characteristics was obtained from the Turkish Meteorological Office. The information consisted of measurements made at two locations: the Ankara Meteorological Office, located 5 km north of the center of the city, and the Etimesgut Airport, situated approximately 15 km west of the city.

The second period of interest for meteorological data was the fall and winter of 1970-71, the period of the inventory of emissions and air quality monitoring. This information was sought to compare prediction of air pollution concentration produced by the mathematical dispersion model with actual measurements of air pollution concentration. Comparison of meteorological conditions portrayed by the 5-year record and conditions of the winter of 1970 were also made. To supplement the data from the two existing stations, a meteorological tower was installed at the Hygiene School (Hifzisihha), located in the center of Ankara. An anemometer, thermoscreen, and thermograph were installed at this site and operated as part of this study.

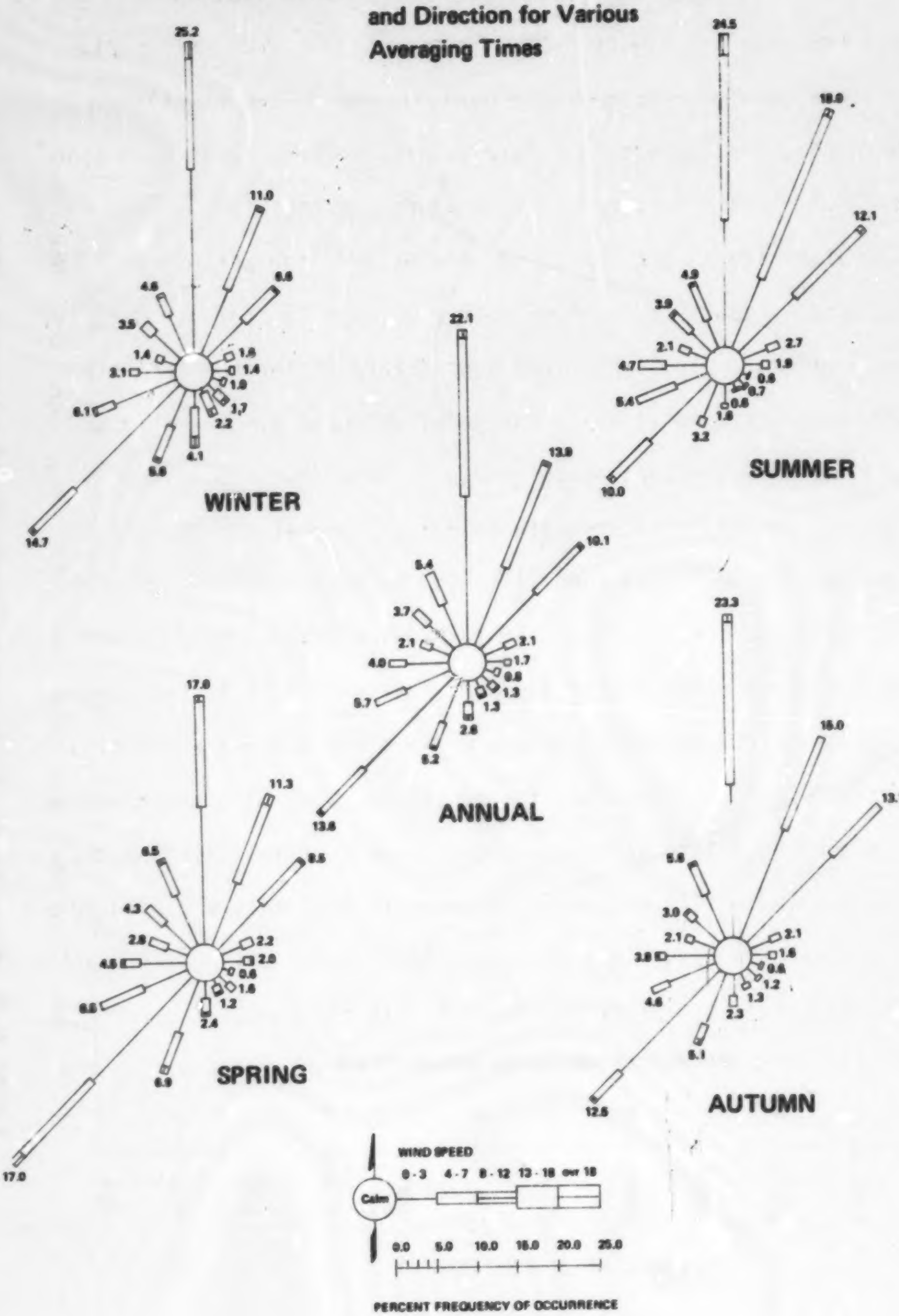
II. Average Meteorological Conditions

A. Wind flows. Seasonal and annual wind roses, based on the measurements taken at the Meteorological Office from 1964 through 1968, are presented in Figure A-28. Throughout the year, northerly surface winds predominate; the secondary maximum is southwesterly. In each season, wind speeds fall mainly into the two lowest wind speed classes. This great frequency of very light surface winds, combined with high stability during the cooler months and high pollution emission rates, results in a large number of days of poor air quality. Prevalence of extremely light winds over Ankara is further indicated by wind speeds measured at an elevation of 300 meters. The average wind speed up to 300 meters above ground is less than 3.5 m/sec.

B. Mixing Height. Another meteorological parameter pertinent to understanding air pollution conditions is the afternoon mixing height, which is defined as the maximum height to which pollutants can be expected to be dispersed during the day. Mixing height is calculated by extrapolating the observed surface maximum temperature adiabatically to the point where it intersects the nighttime, 0000 GMT, temperature trace. Figure A-29 indicates that the average monthly mixing height varies from a low of 900 meters in December to 2500 meters during summer; when the dispersion conditions are favorable. Accompanying the graph of mixing height is a plot of the mean monthly transport wind speed, which is the arithmetic mean of reported wind speed levels within the mixing layer.

C. Atmospheric Stability. Surface observations at Etimesgut were used to determine atmospheric stability. Surface meteorological observa-

FIGURE A–28. Percent Frequency of Wind Speed and Direction for Various Averaging Times



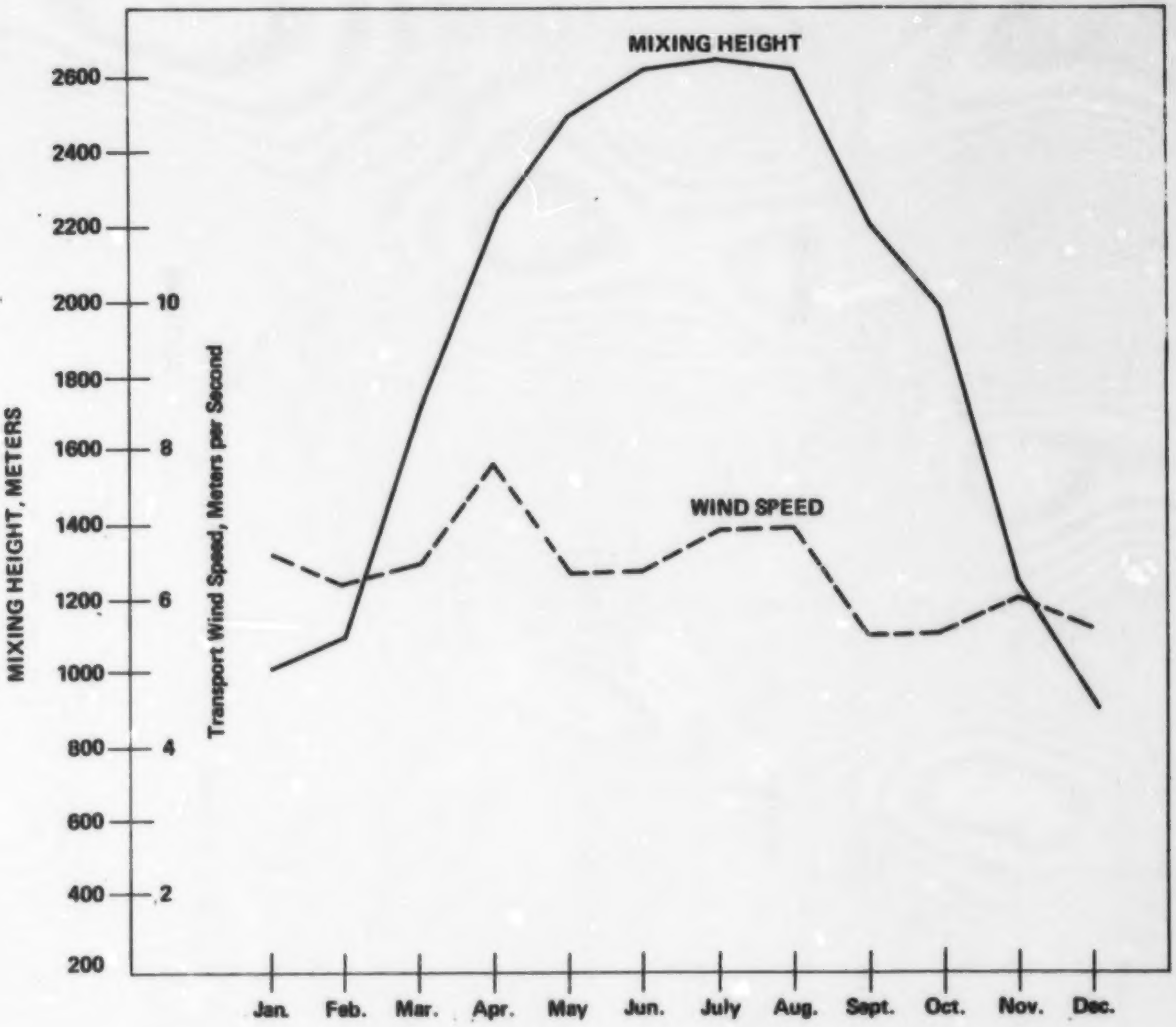


FIGURE A–29. Average Monthly Mixing Height and Transport Wind Speed for Ankara 1964 - 68.

tions recorded routinely every 3 hours were assumed to be representative of the synoptic conditions prevailing over Ankara. The analysis of stability class presented in Figure A-30 was determined by an objective technique devised by Turner, which incorporates wind speed, cloud cover, cloud height, and local time of day. Class 5 stability (high stability) occurs at night when skies are relatively clear and wind speeds are low. Class 4 stability (neutral) can occur at night or during the day when skies are overcast or when wind speeds are strong. The remaining stability classes (1-3) occur only during the daytime.

High stability conditions prevail in Ankara a large proportion of time. Light surface winds and strong inversion conditions at night are in evidence throughout the year.

D. Temperature. The average monthly surface temperature recorded at the Meteorological Office is summarized in Table A-15.

TABLE A-15. Average Monthly Temperature (°C) 1964 - 68

Jan.	-0.4	Apr.	11.0	July	22.5	Oct.	13.1
Feb.	0.3	May	15.3	Aug.	22.3	Nov.	7.9
Mar.	5.9	June	18.9	Sept.	18.2	Dec.	3.9

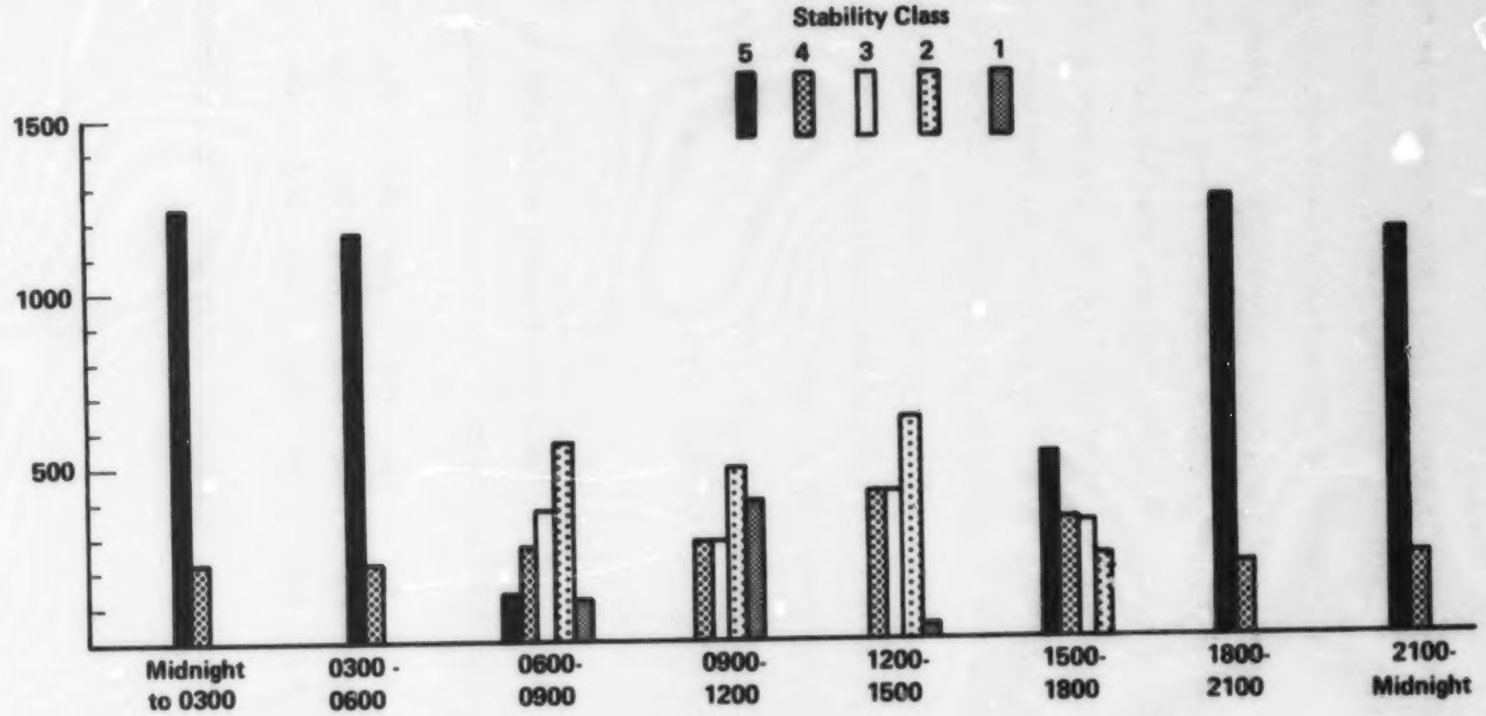


FIGURE A–30. Frequency of Occurance of Stability Class by Hour (3-Hour data, 1964-68).

III. Comparison with Meteorological Measurements of Winter 1970/1971

The data collected during this time period were essentially the same type of meteorological input required to analyze and project air quality conditions, that is, the weather elements needed to determine the relative frequency of stability, wind speed, and direction, as well as the mixing height and air temperature.

In several important respects, conditions in the winter of 1970 deviated from average winter conditions. Temperatures were higher than usual and wind speeds stronger. Both these factors probably caused the pollutant concentrations during the winter of 1970 to be lower than normally expected.

The wind rose of winter 1970 presented in Figure A-31 shows a substantial increase in wind speeds in the third and fourth speed ranges. The direction with the highest percentage of wind flow is northeast; a secondary maximum is in the west-southwest quadrant.

Operation of an additional anemometer at the Hygiene School provided some insight into the variability of wind flow over Ankara. With terrain as uneven as that of Ankara, large differences in wind flow from site to site are inevitable. A comparison of records from the Meteorological Office and the Hygiene School stations confirms this. A computer program tested the significance of the differences in mean wind direction and speed for eight wind sectors (Semord, Valenzuela, 1969). Mean differences between the Meteorological Office and Hifzissihha are shown in Figure A-32. In addition to differences in the mean wind direction, southerly winds are stronger at

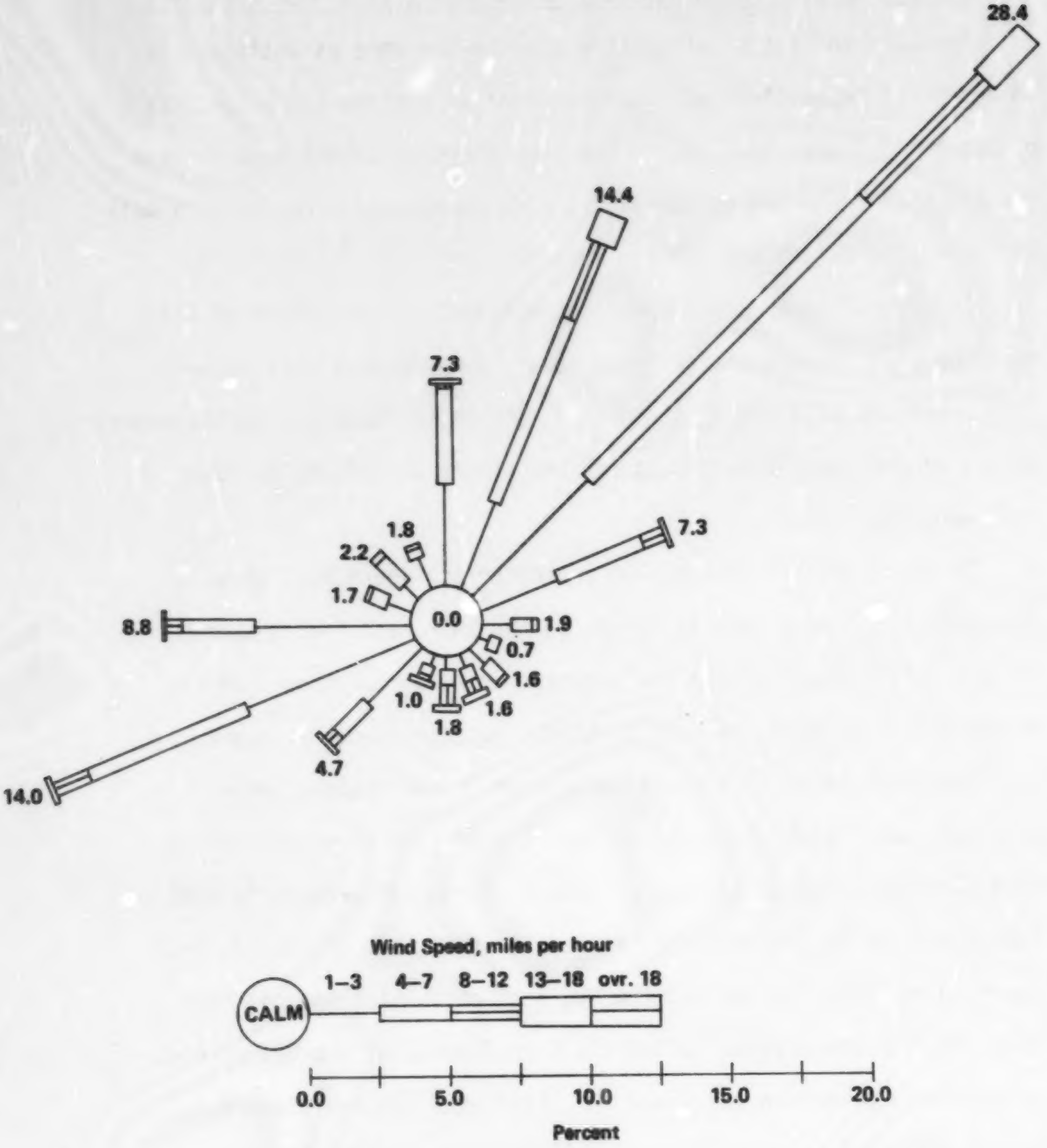


FIGURE A–31. Winter, 1970, Wind Rose for Ankara, Turkey. The Percentage of calms is Distributed in the First Wind Speed Category.

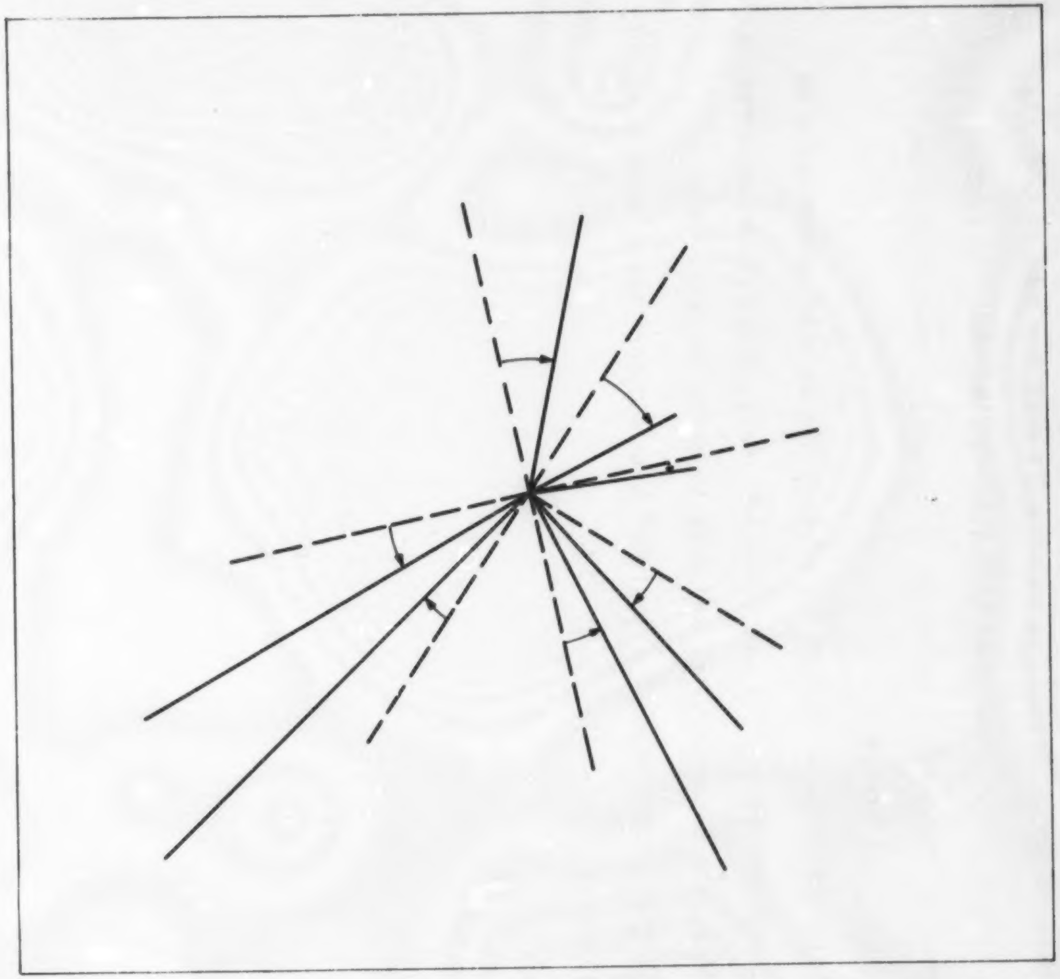


FIGURE A–32. Mean Wind Differences Between the Metoerological Office and Hygiene School (Hifzissihha). Dotted Lines Represent Mean Directions at Meteorological Office. Full Lines are Corresponding Means at Hygiene School and are Drawn in Proportion to Rate of Speed at Meteorological Office.

the Hygiene School than at the Meteorological Office. With winds from the northeast, the average wind speeds at the Hygiene School are lower than the wind speeds observed at the Meteorological Office.

The hourly average temperatures observed at the two sites were nearly identical. This was unexpected, since it was believed that the Meteorological Office, being situated near the edge of the city heat island, would show lower temperatures than the city center. Apparently, the thermal influence of the city extends beyond the Meteorological Office.

The temperature pattern for winter 1970 is quite different from the 5-year average. In winter 1970 the lowest temperatures occurred in December, the 5-year average shows minimums in January. January and February temperatures were higher than the corresponding mean monthly temperatures.

AIR QUALITY MODELING

I. Introduction

A climatological model was selected for making the initial assessment and projections of air quality for Ankara. The model, described in detail in the report of the CCMS Modeling Panel, is limited to providing estimates of long-term averages, i.e., annual and seasonal means. The input consists of an emission inventory and meteorological information; the output is information on air quality levels at selected receptor points. Before the model can be accepted as valid, the results are tested against actual measurements of air quality. When the concentration values produced by the model correlate with the observed data, the calculated values may be calibrated by means of a linear regression equation.

II. Procedure

The preparation of a "working model" for Ankara entailed certain modifications of the basic climatological model. The most notable change was to assume a "box model dilution" instead of a Gaussian plume dispersion. Another alteration was to incorporate estimations of day-night variability in emission rates instead of using a mean 24-hour emission rate.

For sulfur dioxide, calculations of air quality made by use of Gaussian plume dispersion formulation result in considerable over-calculation of SO_2 levels in Ankara. In all cases, the comparisons were made for only the winter quarter. As shown in Figure A-33 the predicted levels are higher by as much as a factor of 5 in the more polluted regions. This may be explained, at least partially, by the extremely uneven terrain of Ankara, which is not accounted for by the model. There is no doubt that emissions from some sources are deflected or blocked by hills, resulting in much lower concentrations downwind than are predicted by the model. Also, emissions from sources situated on hills do not impact on points located in the valleys. Further, areas with extremely low winds, as in Ankara (50% below 1.5 m/sec.) are not well represented by this type of model.

Additional error is introduced by the assumption that emissions change relatively little during a 24-hour period. Although definitive information on day-night variability in emissions was not available, it is known that emission rates were higher during the day and decreased during the night. This pattern is strongly evidenced in Ankara, where fuel consumption rates are much higher during the day than at night (Figure A-34).

With complex terrain and sources at different elevations, calculations of air quality are frequently based on "box model dilution" instead of Gaussian plume dispersion. In the box model, pollution is assumed to disperse vertically throughout the mixing depth instead of spreading gradually, as in the Gaussian plume model. Calculations are accomplished by assigning σ_z a constant value of 0.8 x mixing height. Figure A-35 shows the correlation of observed with predicted values. Use of the box dilution version of the model increases the slope of

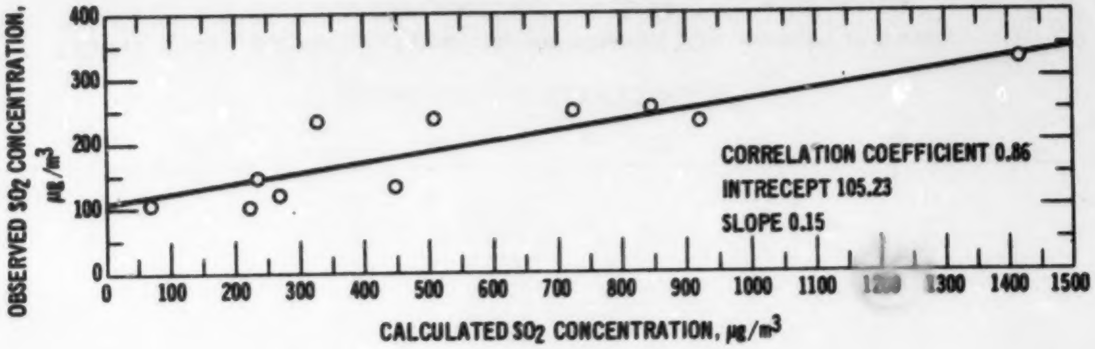


FIGURE A-33. Correlation of predictad and observed SO_2 concentrations using Gaussian plume dispersion and uniform 24 - hour emission rates.

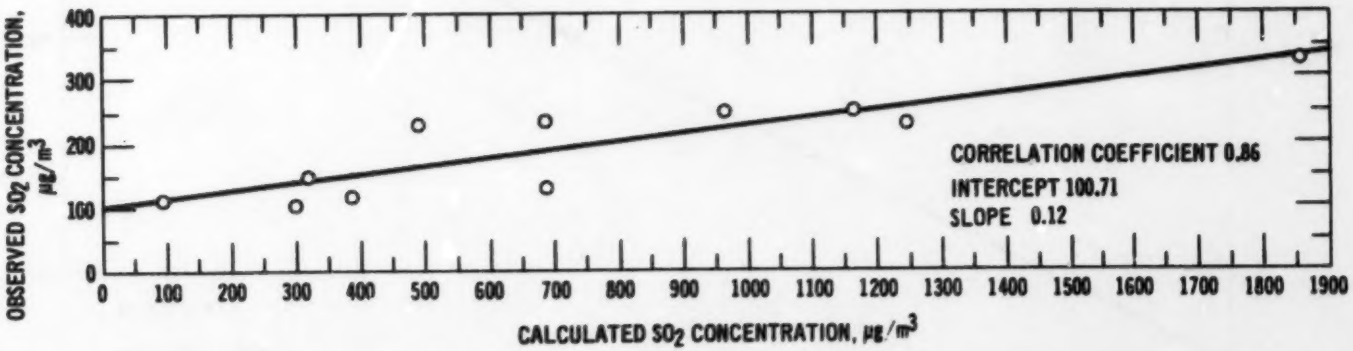


FIGURE A-34. Correlation of predicted and observed SO_2 concentrations using Gaussian plume dispersion and variable 24 - hour emission rates.

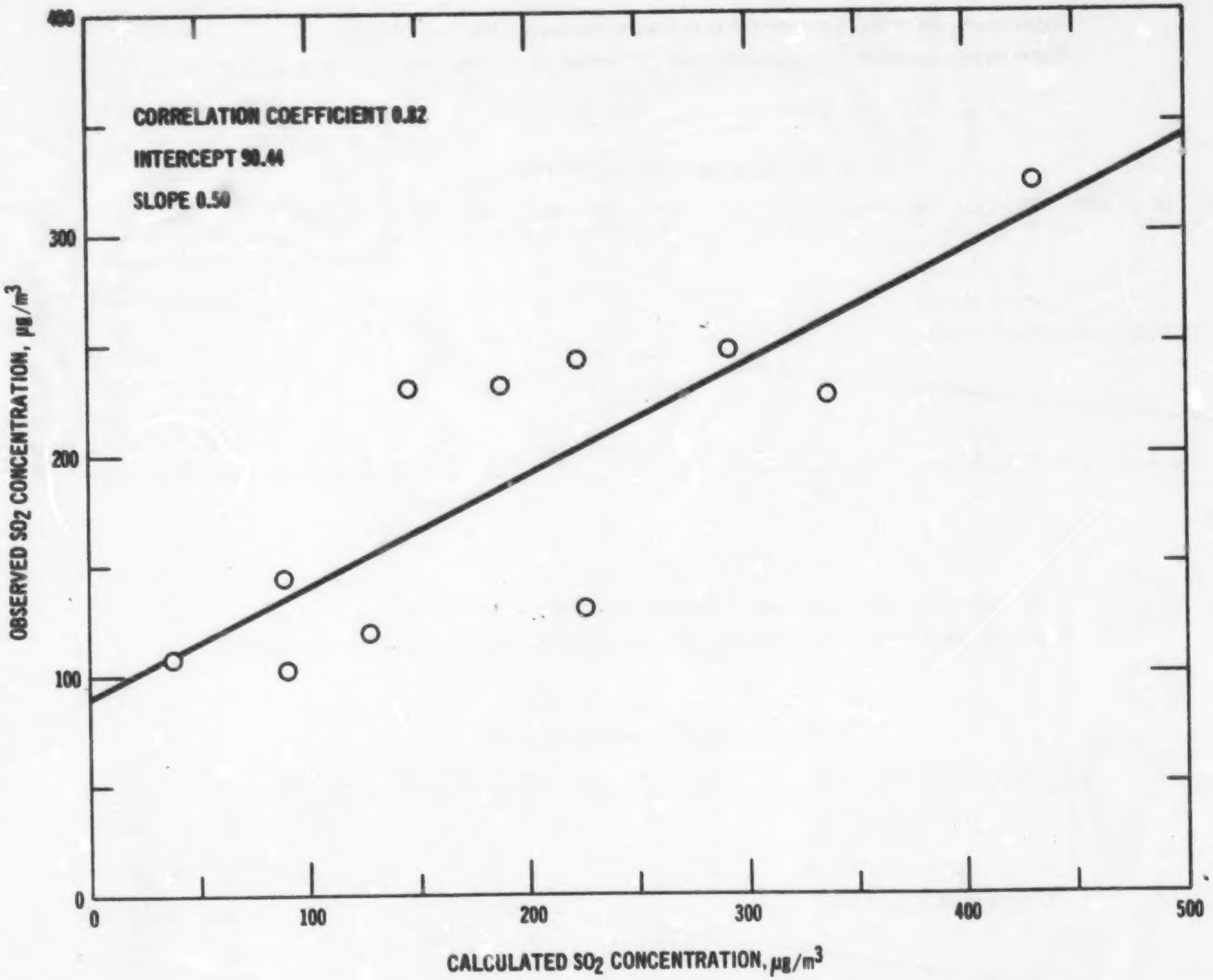


FIGURE A–35. Correlation of predicted and observed SO_2 concentrations using "box model diffusion" and variable 24 - hour emission rates.

the regression line so that calculated values are within a factor of 2 of the observed levels.

A certain over-prediction of SO_2 concentrations may result from the failure to consider the decay rate of SO_2 in atmosphere.

The half-life of SO_2 has not been established, although estimates range from days to tens of minutes. Because of these uncertainties, no decay rate was incorporated in the Ankara model. The use of a decay rate would, of course, lower the predicted values and bring about a closer relationship between observed and predicted values.

The same approach was used in establishing a procedure for predicting suspended particulates. With Gaussian plume dispersion, the correlation of observed to calculated air quality is below the 95 percent significance level, so that there is more than a 5 percent probability that results were due to chance (Figure A-36). This is also true when the day-night variability in emission rates is introduced (Figure A-37). For both of these correlations, the measurements taken at stations 9 and 12 were not included since they appeared to be strongly influenced by sources in the immediate area.

It is quite possible that unusually high natural emissions of pollutants in this dry and dusty region obscures predictions by the climatological dispersion model. Many of the samplers were situated, unavoidably, in locations where, as a result of traffic, wind, and construction, particulate matter was resuspended. The background station, located 15 km north of the city, showed an average concentration of 40.5 ug/m^3. This high level makes it more difficult to

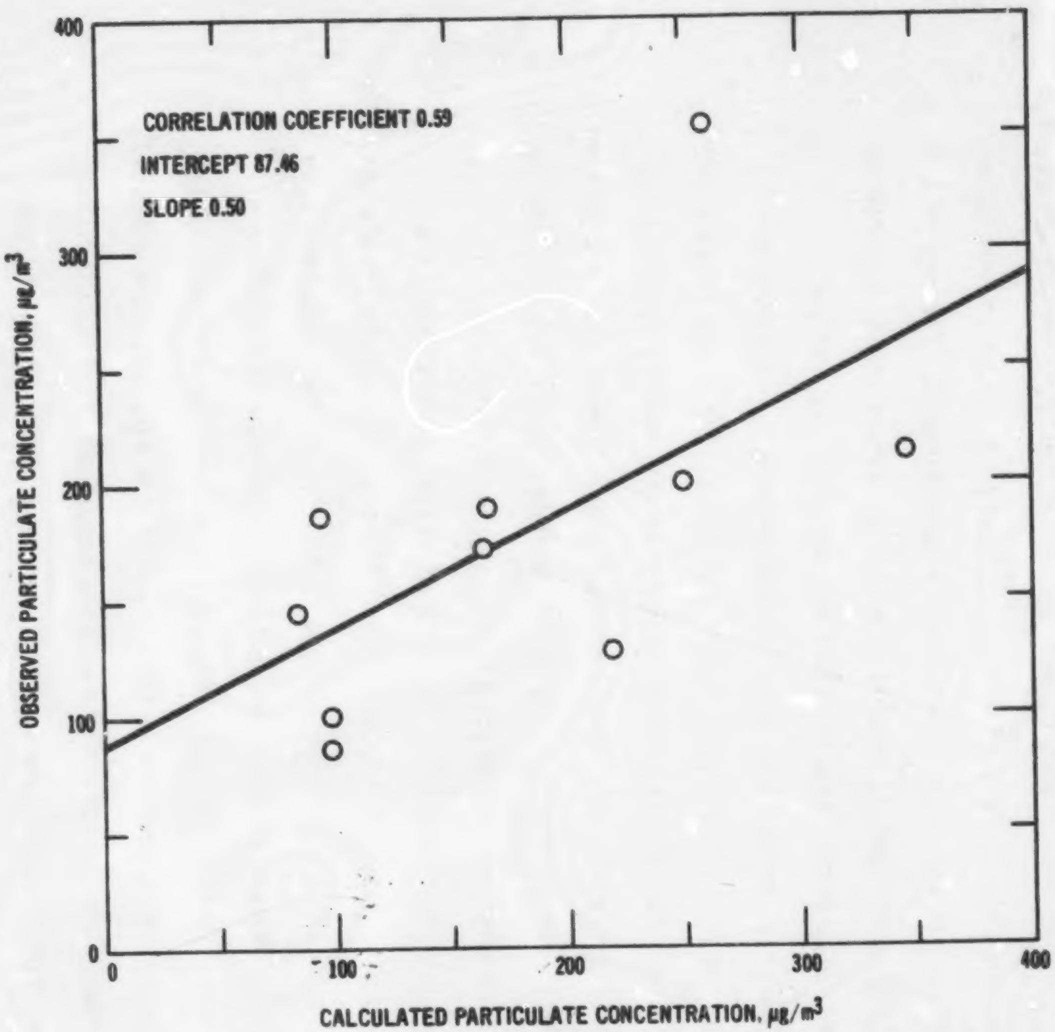


FIGURE A–36. Correlation of predicted and observed TSP concentrations using Gaussian plume dispersion and uniform 24 - hour emission rates.

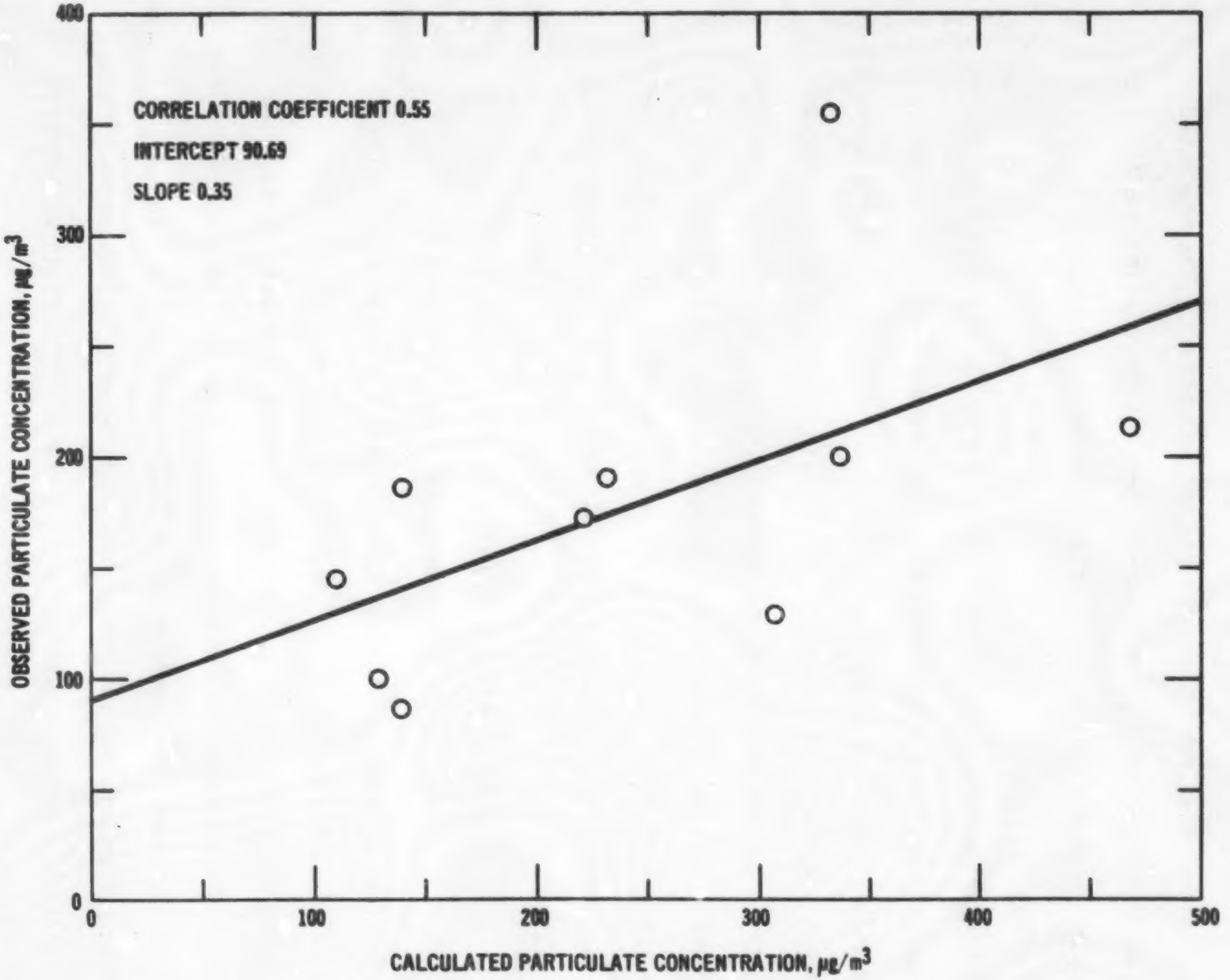


FIGURE A–37. Correlation of predicted and observed TSP concentrations using Gaussian plume dispersion and variable 24 - hour emission rates.

differentiate between background and urban sources of pollution.

Application of the "box model dilution" does not improve the predictions of suspended particulate concentrations. The predicted values are lower than those measured, and the correlating coefficient remains below the 95 percent significance level (Figure A-38).

III. Results

Linear relationships between the observed and predicted pollutant concentrations were established to calibrate the results produced by the model. For SO_2, the linear correlation coefficient is above the 95 percent significance level; for particulate matter it is not. Nevertheless, analyses were made for both pollutants. Because of the poor agreement between calculated and measured values, the predictions of suspended particulate should, for the present, be regarded as tentative.

The predicted values were correlated by use of the following relationships:

$$SO_2\text{: Conc. (ug/m}^3\text{) = 0.50 (Pred. Conc.) + 90 }\mu\text{g/m}^3$$

$$\text{Part.: Conc. (ug/m}^3\text{) = 1.51 (Pred. Conc.) + 76 ug/m}^3$$

Predictions of ambient air quality were made for three time periods: the entire year and the winter and summer seasons. The concentrations, reported as 24-hour averages, are shown as iso-intensity lines. The predictions of sulfur dioxide concentrations for the year and the winter season are shown in Figures A-39 and A-40, respectively. The concentrations during the summer are insignificant. Both cases result in relatively smooth concentrations contours, which is to be expected

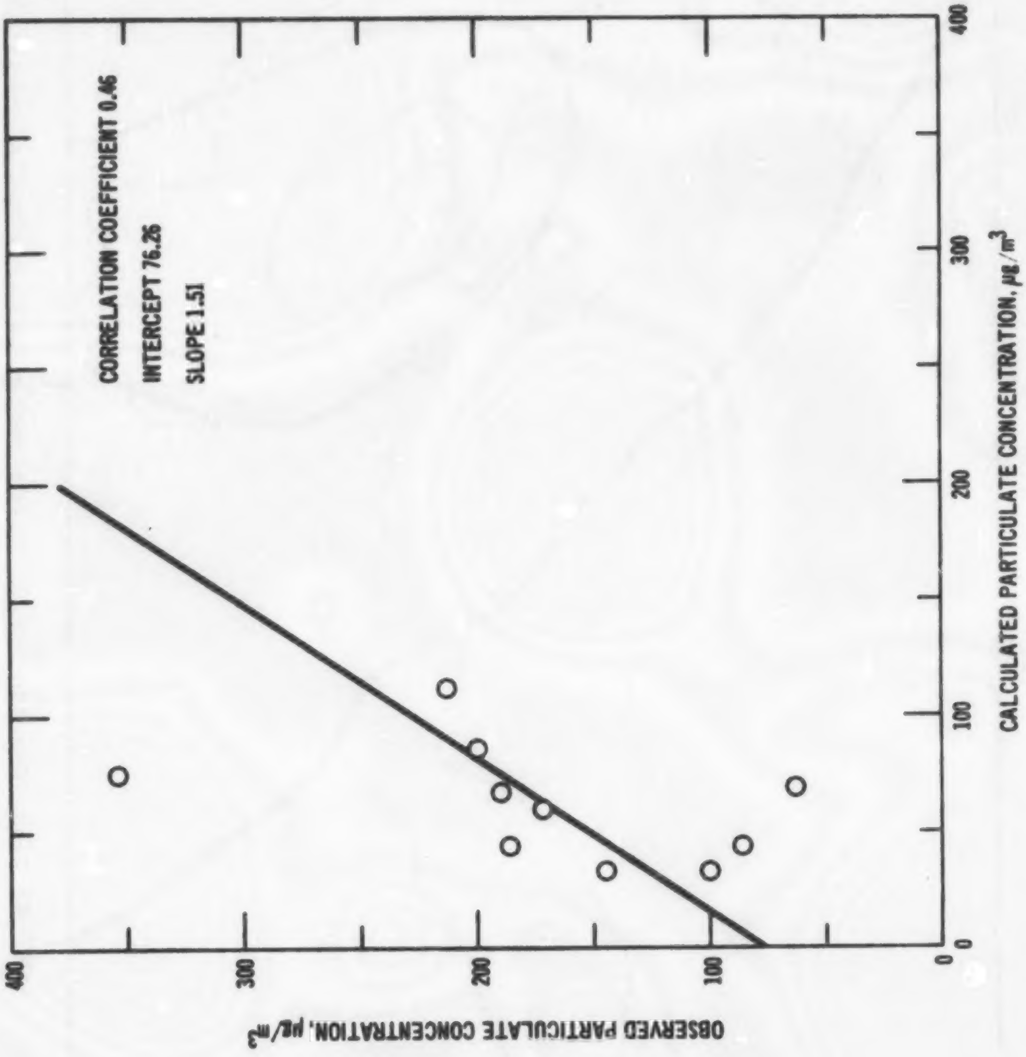


FIGURE A—38. Correlation of predicted and observed TSP concentrations using "box model diffusion" and variable 24 - hour emission rates.

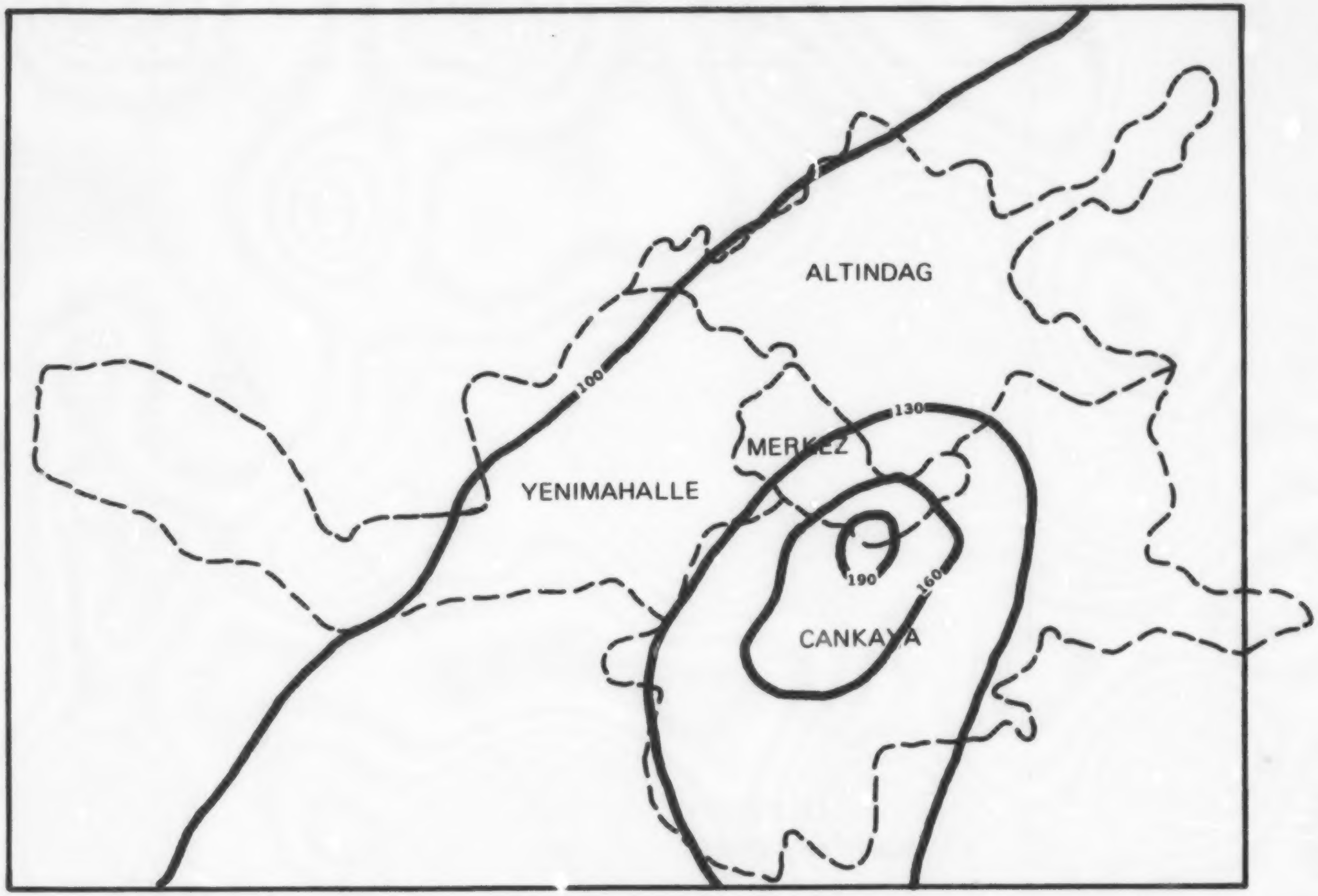

ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
100
130
160
190

FIGURE A–39. Mean Annual Sulfur Dioxide Levels in Ankara Predicted by Model ($\mu g/m^3$).

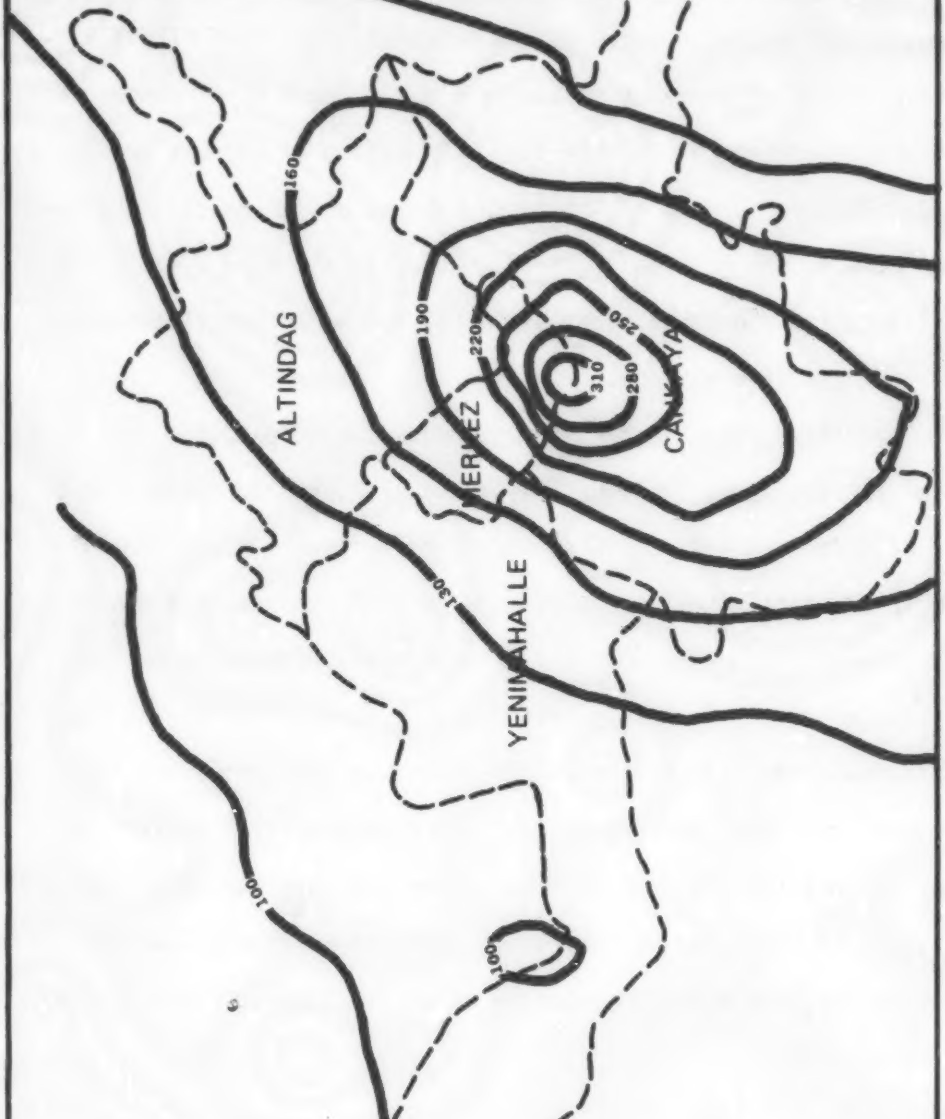

ALTINDAG
MERKEZ
CANKAYA
YENIMAHALLE
100
100
130
160
190
220
250
280
310

FIGURE A–40. Mean Winter Sulfur Dioxide Levels in Ankara Predicted by Model ($\mu g/m^3$).

since the majority of emissions come from area sources and not from individual large emitters. The pattern of predicted concentrations is almost congruent with the emission patterns, displaced slightly because of the prevalence of northerly winds. The highest concentration is centered over the core of the city, the region of highest population density. The contours of SO_2 diminish outward and approach background concentrations some 10-15 km from the center of the city. The predicted maximum concentrations are about 190 ug/m^3 annual average and 320 ug/m^3 winter average.

The predicted annual and winter averages for suspended particulates are shown in Figures A-41 and A-42, respectively. This analysis is derived from calculations that correlate only slightly with observed data. Nevertheless, some general observations can be made. As with sulfur dioxide, the highest levels are found during winter; no significant urban-produced particulate matter during the summer is apparent. High particulate values in the summer can be attributed to natural sources of dust. The geographical pattern is similar to that for SO_2; the maximum occurs over the core area and diminishes outward. The concentration gradient is lower, however, because of the more even distribution of source strengths and natural background levels.

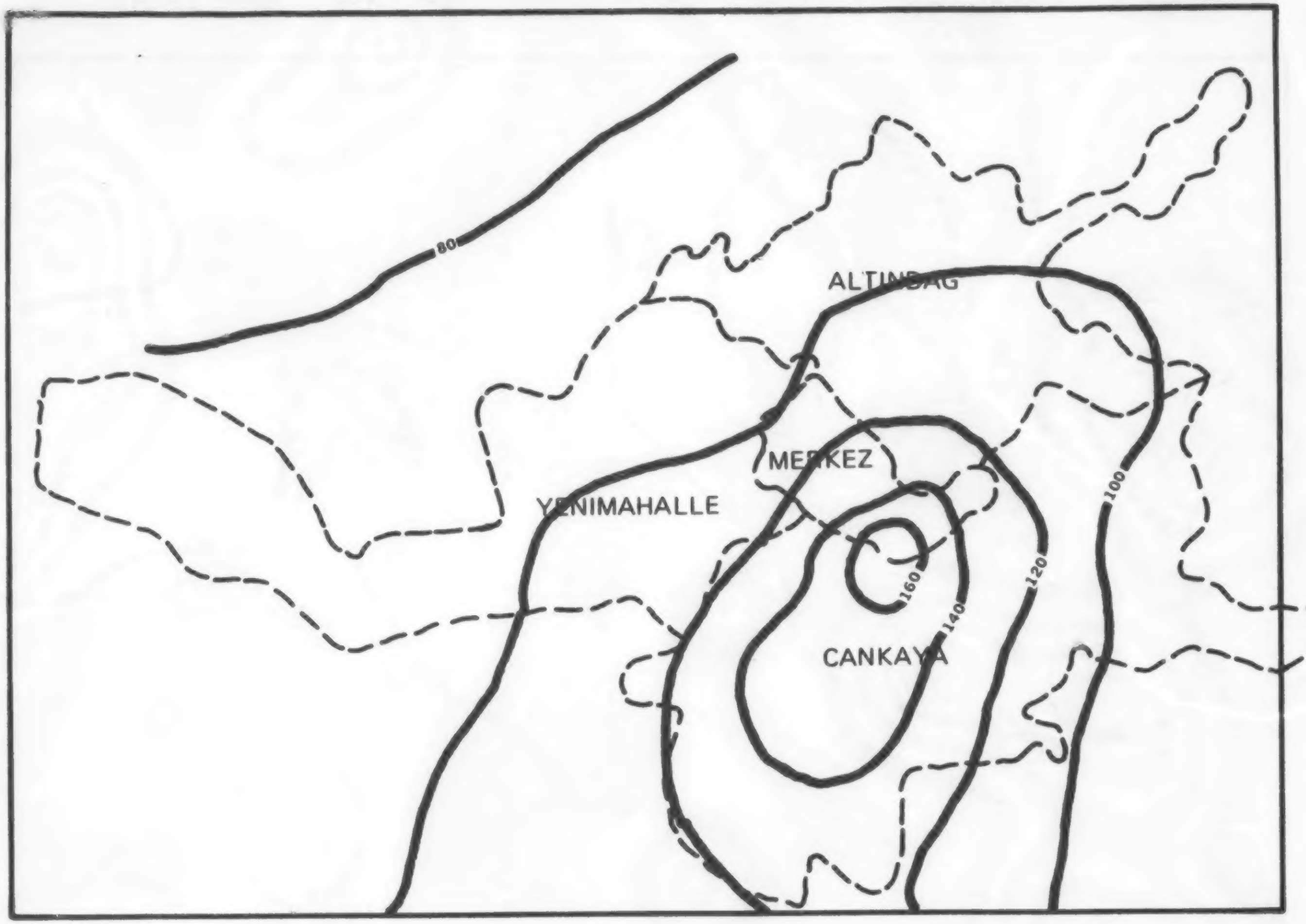

80
ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
100
120
140
160

FIGURE A–41. Mean Annual Suspended Particulate Levels in Ankara Predicted by Model ($\mu g/m^3$).

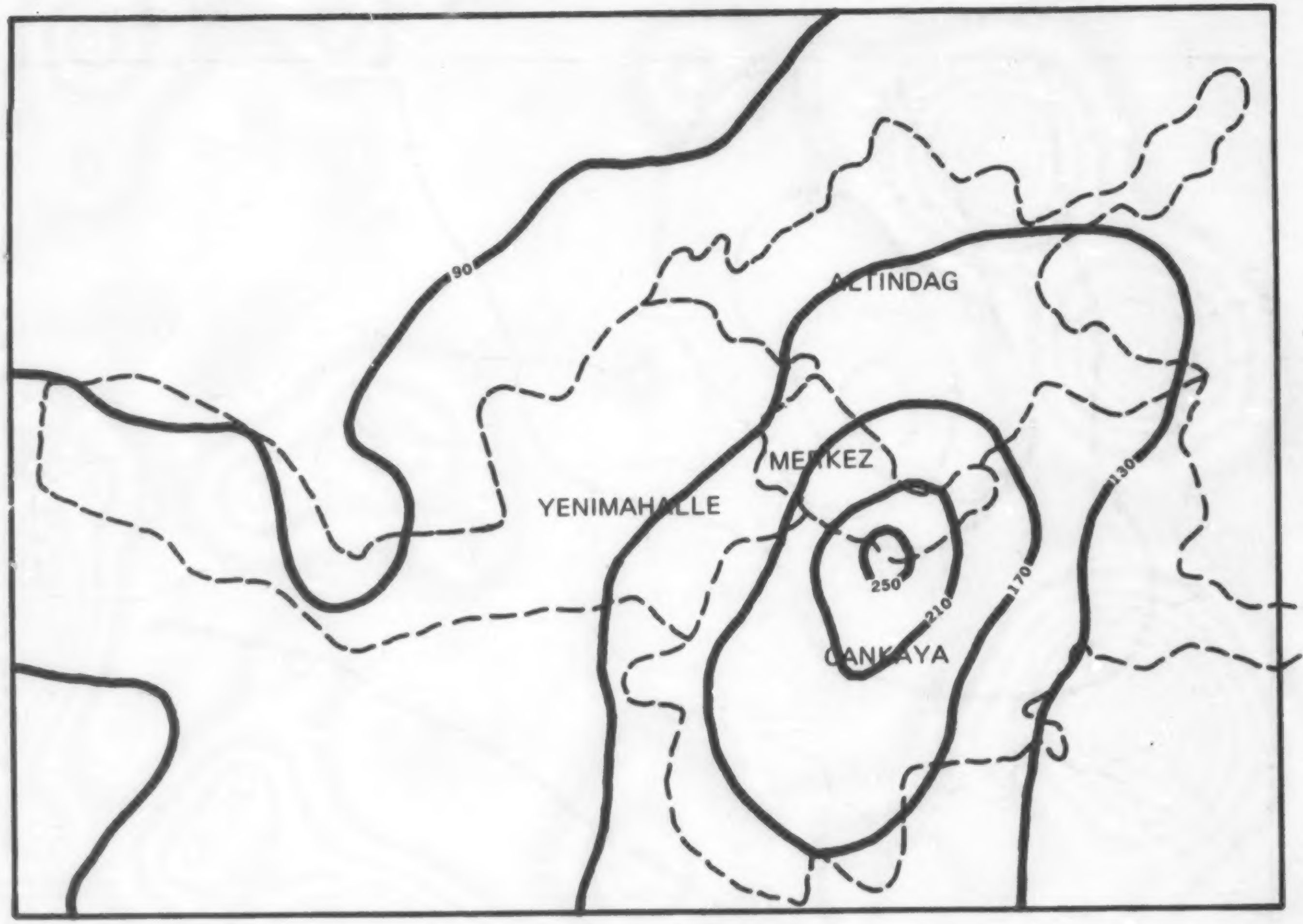

90
ALTINDAG
MERKEZ
YENIMAHALLE
130
170
210
250
CANKAYA

FIGURE A–42. Mean Winter Suspended Particulate Levels in Ankara Predicted by Model ($\mu g/m^3$)

PROJECTIONS OF AIR QUALITY

I. Introduction

Projection of the pollutant concentrations for some time into the future requires (1) a "working model", and (2) projections of air pollutant emissions. Evaluation of different pollution control strategies requires the same procedure; emission forecasts coupled with modeling. For control strategies, however, consideration of control costs must also be incorporated in the evaluation/modeling schemes.

In Ankara, air quality forecasts for sulfur oxides and particulates for the year 1990 were made on the basis of projected population growth, with the assumption that no air pollution control actions are taken. The intent was to illustrate the projection technique and, perhaps more importantly, to show how severe air pollution could become if no control measures were implemented. The availability of a "working model" now for Ankara, will enable the testing of various control alternatives. An illustration of its use is included through projections made on basis of assumed control tactics, i.e., that effective in 1980 all fuels will contain a maximum of 1 percent sulfur and that particulate matter from household furnaces will be eliminated through the use of briquettes instead of coal. Modeling of the other three pollutants was not performed.

This section of the report describes the procedures used in projecting the emissions to the year 1990 and presents the results of both projected emissions and air quality (air quality only for sulfur oxides and particulates).

II. Estimation of Emissions

The basic approach used in projecting emissions for Ankara was to develop or assume various growth factors and apply them to the 1969 emission inventory results. A major difficulty was encountered in forecasting the "placement" of pollution sources within the study area. Whereas general estimates were available on expected growth of population and industrial activity, the areas where future development will take place have not been defined. In light of this, the projections must be viewed with extreme caution. As more information becomes available, the projections made here should be modified.

A. Expected Growth and Development. Detailed and comprehensive development plans for the City of Ankara, although in preparation, were not available. Similarly, forecasts dealing with the expected fuel patterns, refuse disposal, and travel have not been extensively developed. An indication of future growth could, however, be derived from certain statistics that have been compiled by various groups and individuals in Ankara. These include population projections, forecasts of expected employment distribution, and estimates of needed public transportation.

Projections of population, made by the Directory of the Census, shows an extremely rapid increase from 1,200,000 in 1970. As shown in Figure A-43, a more rapid growth is predicted for the City of Ankara than for the remainder of the Province. Although projections have been developed for the four subprovinces, detailed population densities have

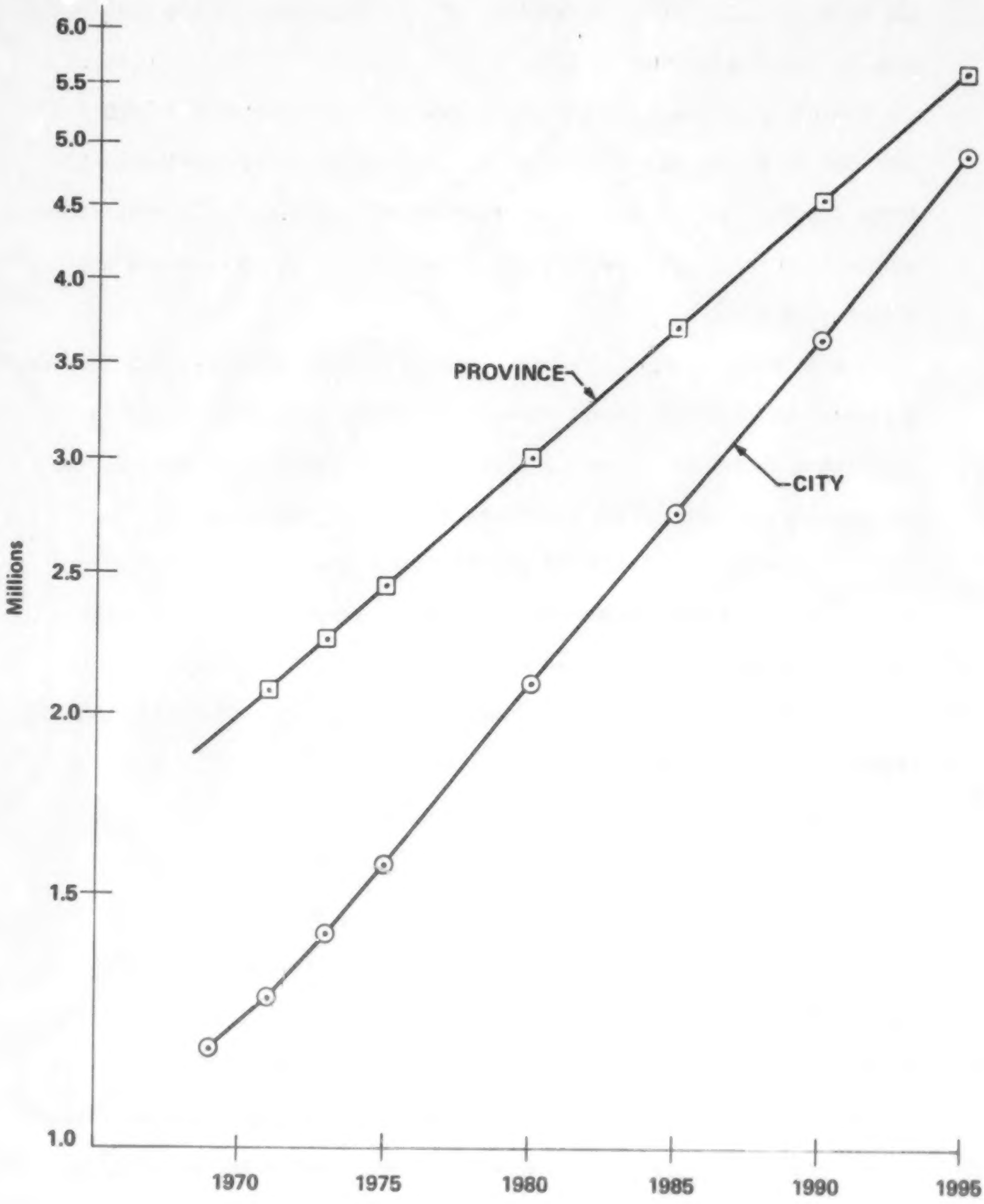


FIGURE A–43. Ankara Population Projections

Source: Directory of the Census

not been derived. Also, directions of land additions to the city have not been predicted in detail.

The distribution of the working population in Ankara for 1965 and 1985 is presented in Table A-16. No drastic shifts in the working force for the various employment sectors is predicted. A slight increase in the industrial production group as well as in the government and military is shown.

The Scientific and Technical Research Council of Turkey has provided estimates of expected travel demands by public conveyances. Table A-17 shows the expected number of daily trips required as well as the number of buses and dolmus needed to meet these travel needs.

B. Procedure for Calculating Emissions. The emission projections were made by applying growth factors to the 1969 inventory data. Emissions from stationary fuel combustion for 1990 were estimated by extrapolating from the 1969 fuel quantities, with the following assumptions:

1. Distribution of the various fuels for domestic uses will remain unchanged. The quantity of each fuel will increase by 210%, which is the expected increase of total population.

2. Distribution of the various fuels for commercial-institutional-governmental uses will remain unchanged, the quantities increasing proportionally to population growth (210%).

3. Distribution of the various fuels for industrial uses will remain the same as in 1969. Increase in consumption is projected at

TABLE A-16

DISTRIBUTION OF WORKING POPULATION IN ANKARA

	Working Population (percent) 1965	1985
Agriculture	3.9	4.7
Mineral Extraction	0.2	0.2
Construction	10.1	12.6
Transportation	7.4	7.4
Government, Military and Other Services	44.0	47.7
Industrial Production	14.6	18.8
Retail and Banking	11.0	8.7
Unknown	8.8	—
TOTAL	100.0	100.0
Total Employment	310,000	1,290,000

Source: Regional Planning Office

TABLE A-17. Expected Travel Needs For Ankara

	People Requiring Daily Transportation	Dolmus (Shared Taxis)	Buses
1969	400,000	19,400	300
1990	2,600,000	100,000 +	1500 +
ratio $\frac{1990}{1969}$	5.5	4.2 +	4.0 +

350% over the 21-year period. A higher rate of increase is allocated due to the expected growth of industrial activity as evidenced by the projected increase in industrial employment.

4. Most of the electric power will continue to be generated well outside the Ankara region.

5. Sulfur and ash content of fuels will remain unchanged.

6. Additional pollution control devices will not be installed.

7. Emission factors used for estimating 1969 emissions also apply to 1990 sources.

The emissions from transportation sources were projected according to following assumptions:

1. Motor vehicle travel will increase by 510% (a more rapid rate is forecast because of expected industrial development). A 3% annual increase above population growth rate was assumed. This was estimated on basis of projected travel requirements as reflected by estimated requirements for dolmus and buses.

2. Although not likely, it has been assumed that automobile exhaust will not be controlled. In effect, then, this projection shows the worst case.

3. The operation of railroads was assumed to increase at a rate comparable to population growth. The use of coal will be eliminated and replaced by diesel fuel at least by 1990.

Solid waste generation and requirements for disposal are expected to increase at a substantially faster rate than that forecast for population growth. In 1969, approximately 250 kg. of refuse was generated per person; in 1990 it is estimated that this will increase to about 450 kg. It was assumed that 50% of waste would still be disposed of by open burning.

Information on the types of industries that will locate in the Ankara area was not available. It was assumed that industries will be limited to the types currently present increasing in size by about 350 percent by 1990.

The distribution of sources and emissions throughout the area were made on basis of availability of vacant land and current and projected population densities. More than likely, severe modifications will be necessary as more definitive development plans are made available.

C. Results. The predicted 1990 emissions for Ankara are tabulated and compared to 1969 totals in Table A-18 and illustrated in Figure A-44. An increase of almost 250 percent is forecast for both, the oxides of sulfur and particulate matter. Much greater increases are forecast for CO, hydrocarbons and oxides of nitrogen, primarily because of increased use of automobiles. All of the pollutants are expected to increase more rapidly than population. It is extremely important to add that these projections are based on the assumption that (1) same general patterns of pollution sources will exist and (2) air pollution control measures will not be implemented.

Table A-19 shows the forecast 1990 emissions by source category. Since most of the individual predictions were based on the continuance of current emission patterns, the same general distribution is shown for

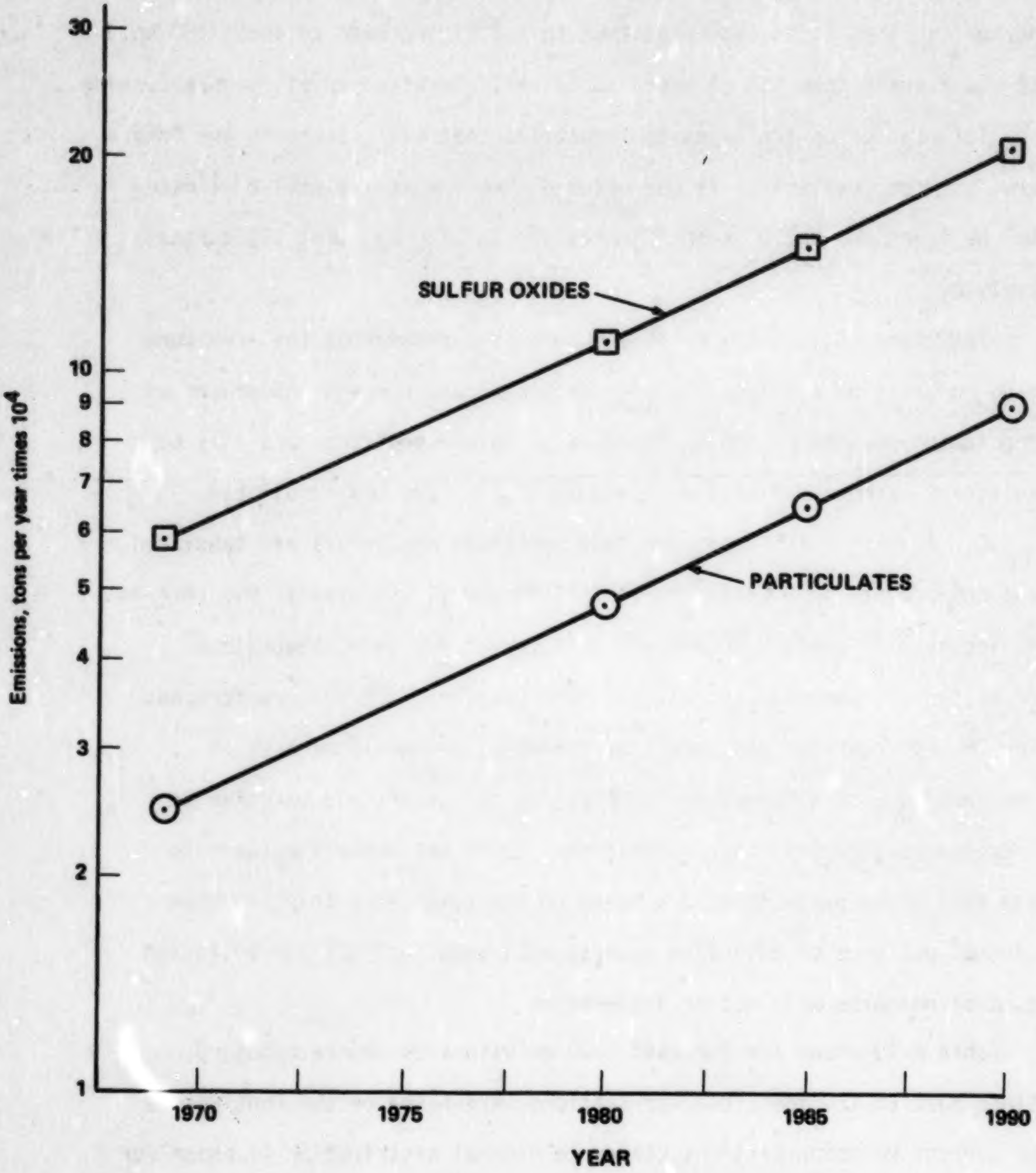


FIGURE A–44. Emissions Projections, Ankara, Turkey

TABLE A–18

COMPARISON OF 1969 AND 1990 AIR POLLUTANT EMISSIONS – ANKARA, TURKEY

Pollutant	Emissions (10^3 Kg/yr.) 1969	Emissions (10^3 Kg/yr.) 1990	Percentage Increase (1969 – base)
Sulfur Oxides	57,600	199,600	246
Particulates	23,000	88,200	283
Carbon Monoxide	73,400	381,500	420
Hydrocarbons	16,400	82,800	409
Oxides of Nitrogen	12,600	50,250	308

1990. The major sources are the use of coal and fuel oil in industrial, residential and governmental facilities, and motor vehicle travel.

The emission estimates from the stationary fuel combustion were based on the expectation that in 1990 the energy demands of Ankara will be met through the use of approximately 2 million tons of coal, nearly 0.5 million tons of coke, 1.5 million tons of fuel oil, and over 200 million cubic meters of gas.

As estimated 600,000 tons of gasoline and nearly 100,000 tons of diesel fuel is expected to be consumed by motor vehicles in Ankara in 1990. This was based on the expected travel demands, and the number of buses and dolmus required to transport people from home to work and to stores as well as an increase in the per capita travel from 1969 to 1990. Emissions from this category are estimated to be 312,000 tons of carbon monoxide, 25,800 tons of oxides of nitrogen and 54,300 tons of hydrocarbons.

TABLE A-19

SUMMARY OF AIR POLLUTANT EMISSIONS IN THE ANKARA STUDY AREA, 1990

(10^3 Kg/year)

Source	Sulfur Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
Transportation					
Road Vehicles	870	1,160	311,650	54,000	25,290
Other	400	150	400	300	500
Subtotal	1,270	1,310	312,050	54,300	25,790
Stationary Fuel Combustion					
Industry	52,000	22,800	530	400	7,200
Residential	56,500	20,100	27,700	5,700	3,650
Commercial – Institutional, Governmental	75,700	14,400	320	500	10,100
Electric Generator	4,800	5,500	140	100	1,050
Subtotal	189,000	65,800	28,690	6,700	22,000
Refuse Disposal	410	6,600	34,900	12,300	2,460
Industrial Processes	8,900	14,500	5,900	n	n
Evaporative Losses	—	—	—	9,500	—
GRAND TOTAL *	199,800	88,200	381,500	82,800	50,250

* rounded

The disposal of solid waste by open burning is estimated to emit about 410 tons of sulfur oxides and 6,600 tons of particulates annually. The emissions of particulates account for about 8% of total particulate emissions and thus is an extremely significant source of pollution especially if it continues to originate from a single location--the open burning dump.

The emissions from industrial processes are projected to account for about 9,000 tons of sulfur oxides and 14,500 tons of particulates. As is the case today, the manufacturing of cement, grain handling, gas manufacture and the asphalt industry will continue to be the major contributors.

III. Projection of Air Quality

Using the previously described emission projections and the "working model," an estimate of the pollution patterns and levels for 1990 was obtained. Figures A-45 and A-46 show the iso-intensity contours of annual averages for sulfur dioxide and suspended particulates, respectively. It is clearly evident that not only the maximum concentrations are increased, but areas of the city previously not subjected to severe levels will be by the year 1990.

For sulfur dioxide, the center of the maximum is expected to shift somewhat--from Hifzissihha to Harpokulu. The projected maximum emissions are estimated to occur about 1 km. north of Harpokola. Although total emissions are forecast to increase by a factor of four, the maximum annual mean concentration is calculated to increase only from 190 ug/m^3 to 280 ug/m^3. This is to be expected, since the center portion of the city

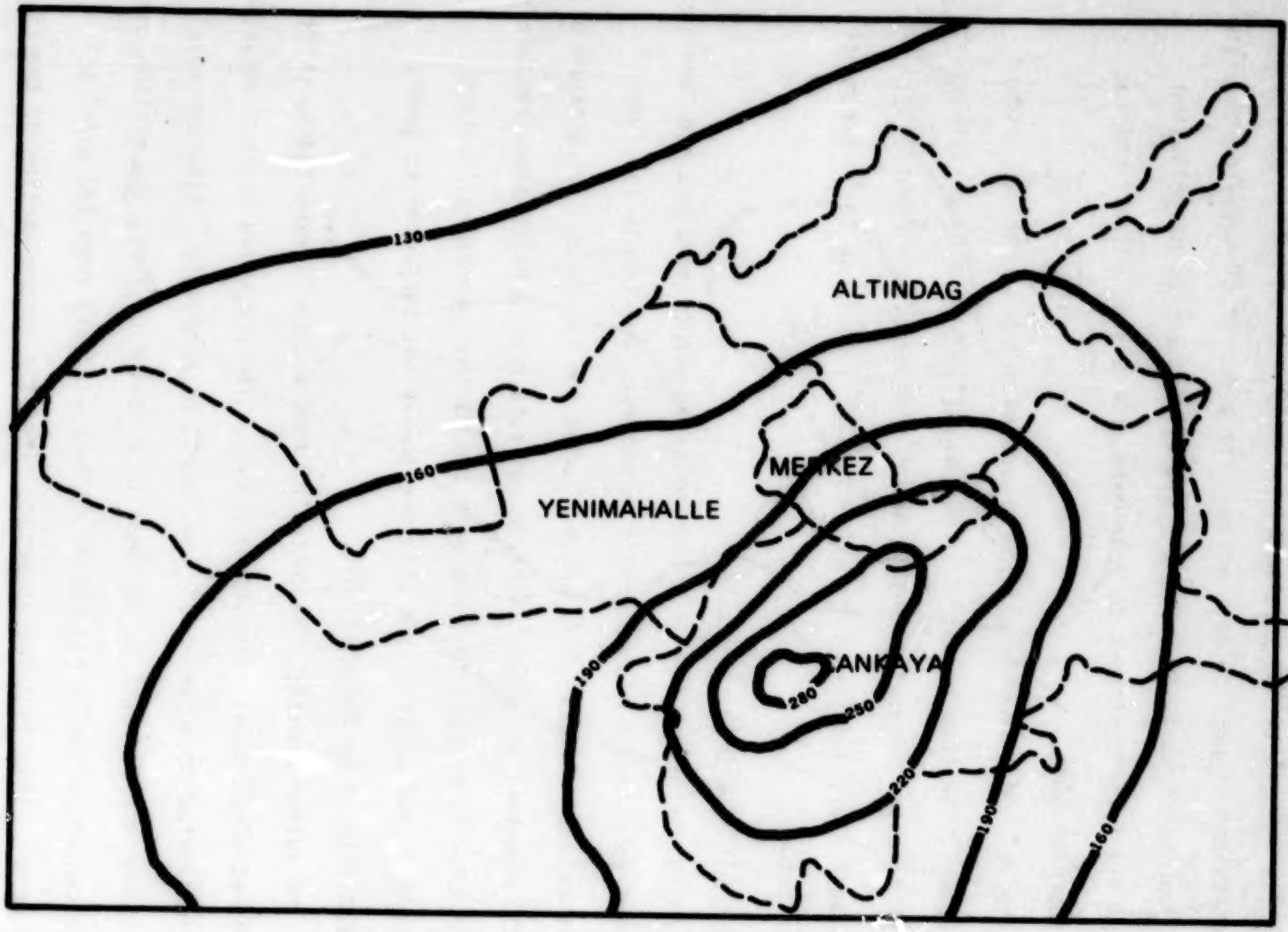

130
160
190
220
250
280
ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
160
190

FIGURE A–45 Mean 1990 Annual Sulfur Dioxide Levels in Ankara predicted by Model ($\mu g/m^3$).

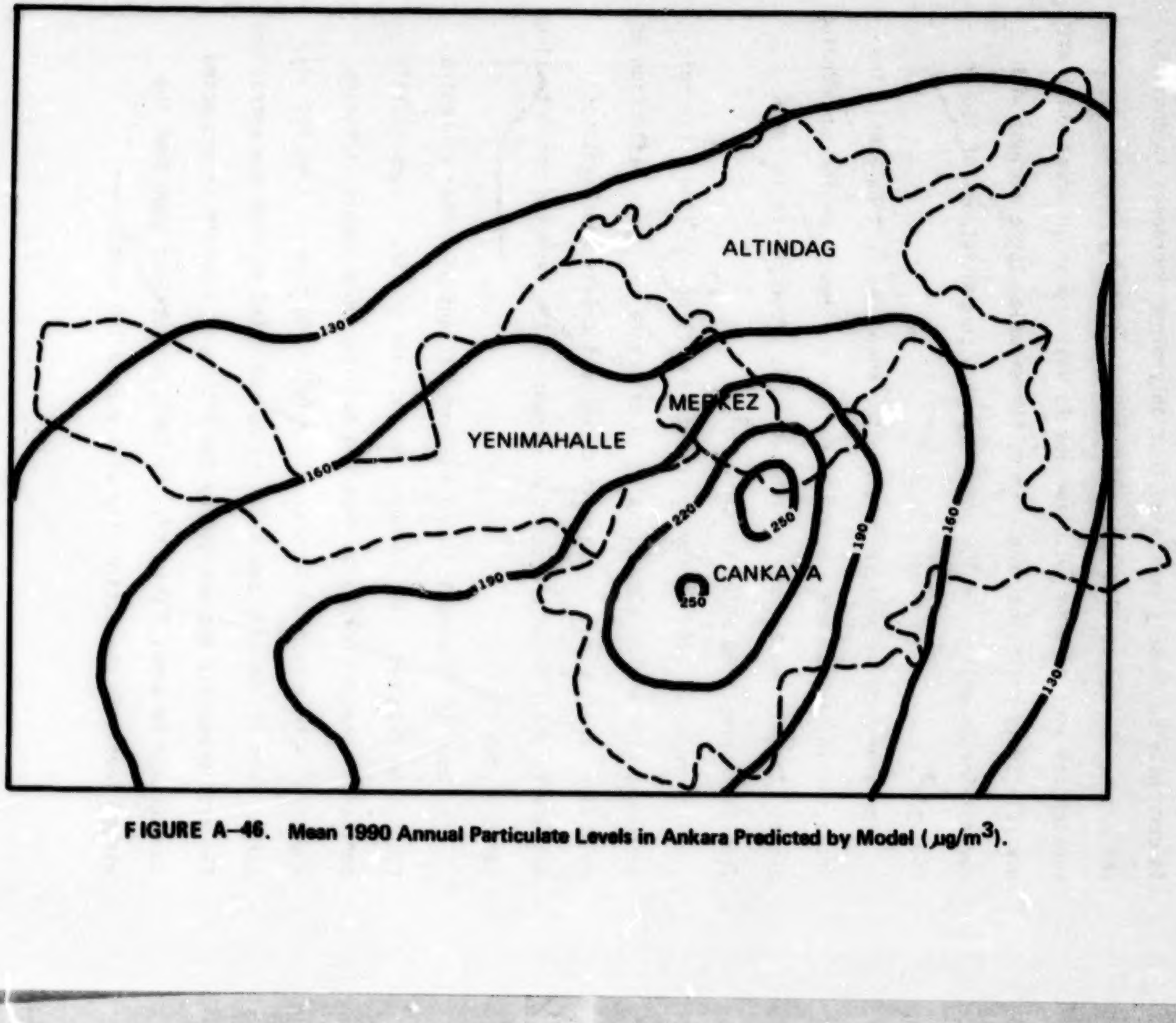

ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
130
160
190
220
250
250
190
160
130

FIGURE A–46. Mean 1990 Annual Particulate Levels in Ankara Predicted by Model ($\mu g/m^3$).

is currently so densely populated that only minor increases in density can occur. As the population spreads from present day Ankara, substantial increases in pollution levels will appear in areas which are now relatively pollution free. Thus, for example, large regions with current levels well below 100 ug/m^3 may show concentrations of 150 to 200 ug/m^3.

The same general pattern is shown for suspended particulates. The increases in maximum average concentrations are less than for surrounding areas. The maximum average concentration is projected to increase from the current 160 ug/m^3 to 250 ug/m^3.

The projected air quality distribution will be modified by terrain features. The higher elevations south of Ankara may cause deflection of pollution trajectories eastward which would increase the levels of pollutants above those projected and reducing the expected concentrations south of the city.

As shown in Figures A-47 and A-48 predictions of winter concentrations show extremely high values. In the case of TSP, a substantial portion of central Ankara is expected to experience levels exceeding 300 ug/m^3 with a maximum of over 410 ug/m^3. The same is true for SO_2. Large areas of the city are shown to be subjected to high concentrations. The area presently encompassed by the 190 ug/m^3 isopleth is projected to increase to about 350 ug/m^3. By 1990, projections show that the winter levels in the entire city will exceed 190 ug/m^3.

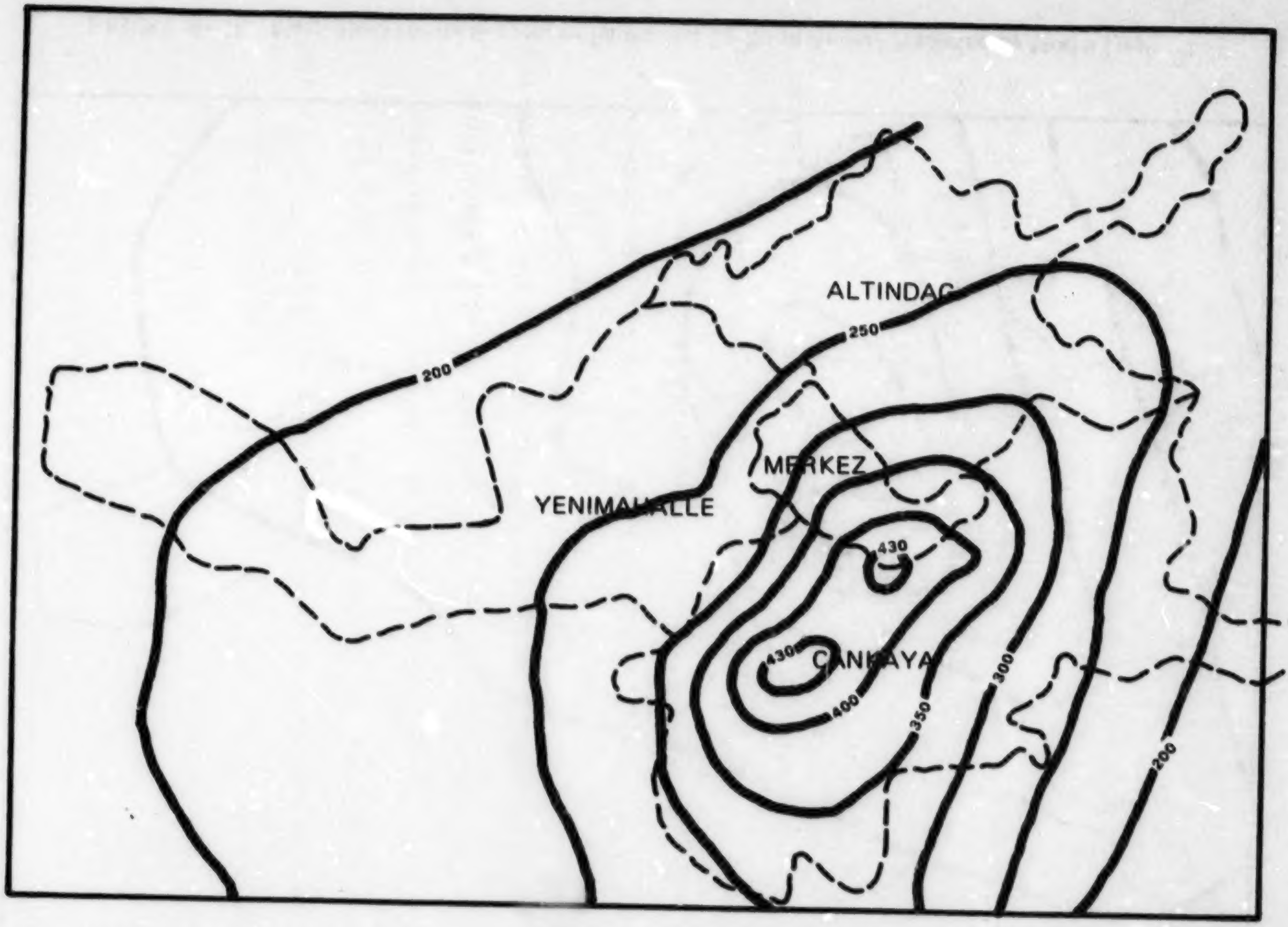

ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
200
250
300
350
400
430
430
200

FIGURE A–47. Mean 1990 Winter Sulfur Dioxide Levels in Ankara Predicted by Model ($\mu g/m^3$).

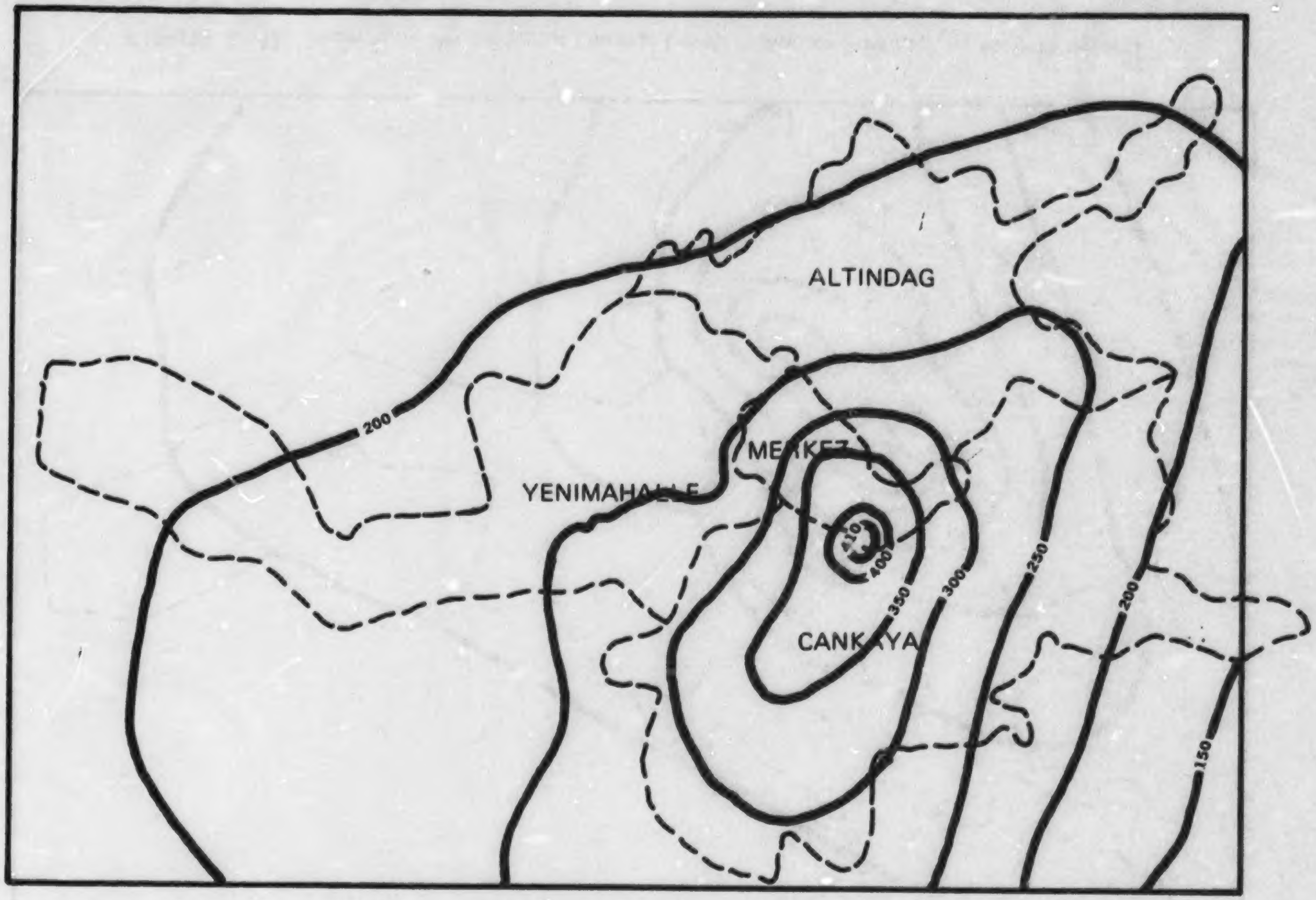

ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
200
250
300
350
400
410
200
150

FIGURE A–48. Mean 1990 Winter Suspended Particulate Levels in Ankara Predicted by Model ($\mu g/m^3$).

IV. Application of a Control Tactic

How emission projections and the model can be used to evaluate the impact of possible control alternatives is illustrated through two different abatement tactics. In order to project the effect of limiting sulfur content of fuels on the SO_2 pollution projections of emissions and air quality were made on the basis of an imposed one percent maximum sulfur content. If briquettes supplant the use of lignite in household furnaces a reduction in suspended particulate concentrations will ensue. To illustrate the impact of this action on ambient particulate concentration, projections assuming total use of briquettes by households were made. For both of these cases, it was assumed that a gradual change-over will occur culminating in a complete switch-over by 1980.

The projected emissions as a result of these actions are shown in Figure A-49. For sulfur dioxide, the decrease attained due to this restriction will be offset by the late 1980's when increased fuel consumption will cause emission rates to rise above current levels. Projected levels between 1970 and 1980 are entirely dependent on the rapidity with which the switch-over is implemented.

For particulate matter a less noticeable change is forecast. This is not surprising since the restriction is applied to a smaller portion of particulate emitting sources.

The effect that these control tactics could have on the 1990 average annual concentrations is shown in Figures A-50 and A-51. In the case of sulfur dioxide, the maximum average concentration is projected to decrease from about 250 ug/m^3 to about 170 ug/m^3. Although some reductions

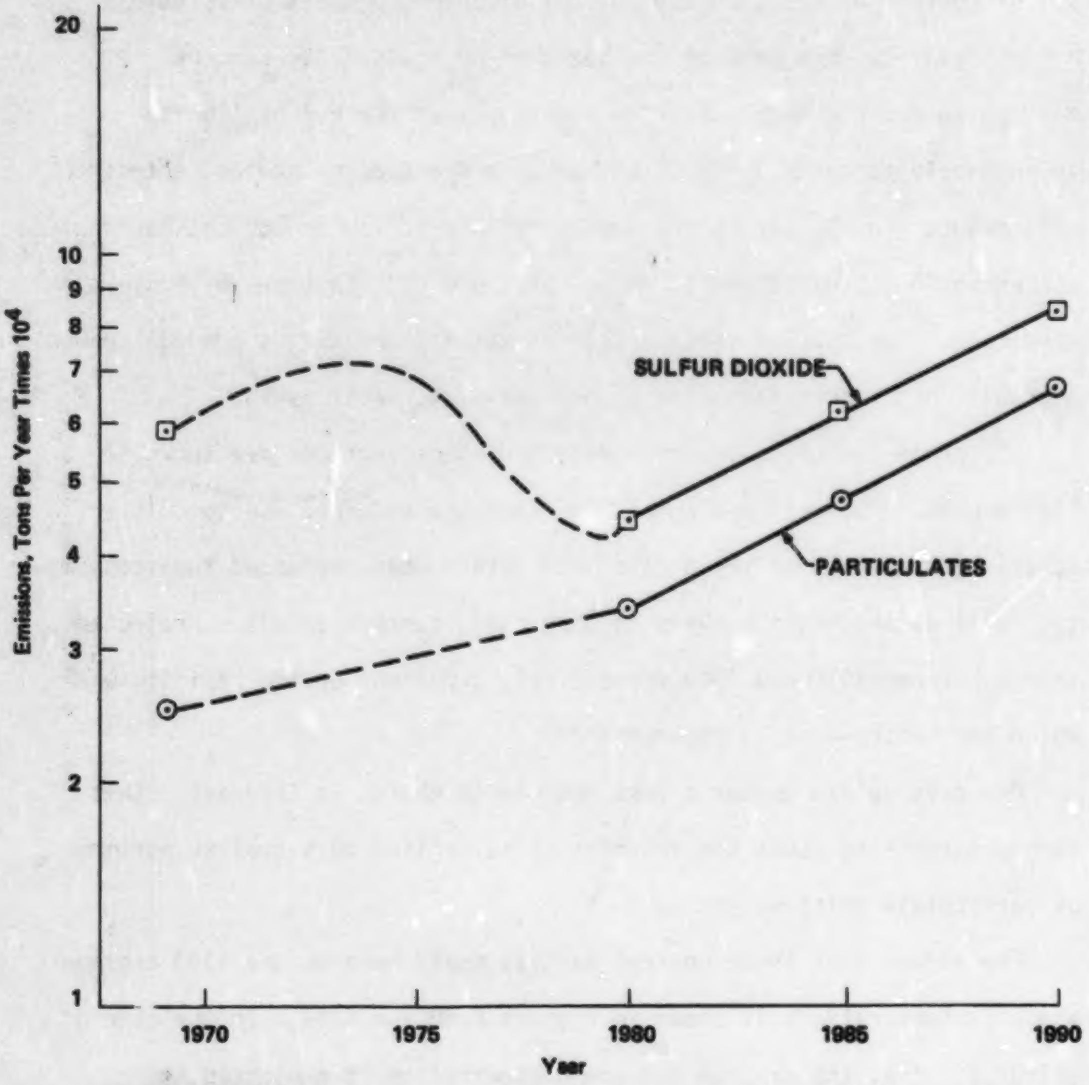
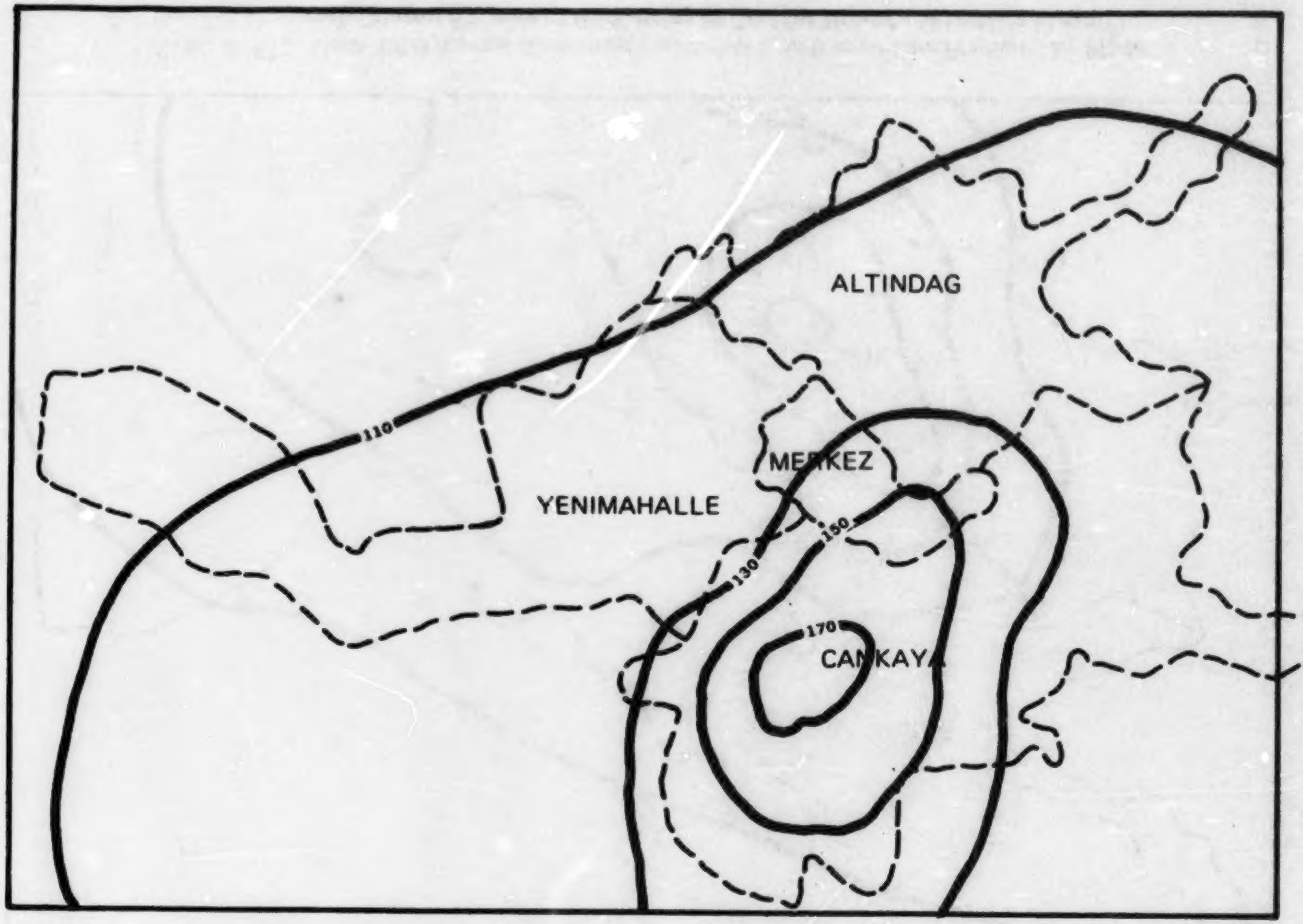


FIGURE A–49. Projected Emissions; Assumes the Use of 1% Fuel and Coal Briquetting for Home Heating by 1980.



ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
110
130
150
170

FIGURE A–50. Mean 1990 Annual Sulfur Dioxide Levels in Ankara Predicted by Model with Control Strategy of 1% Sulfur ($\mu g/m^3$).

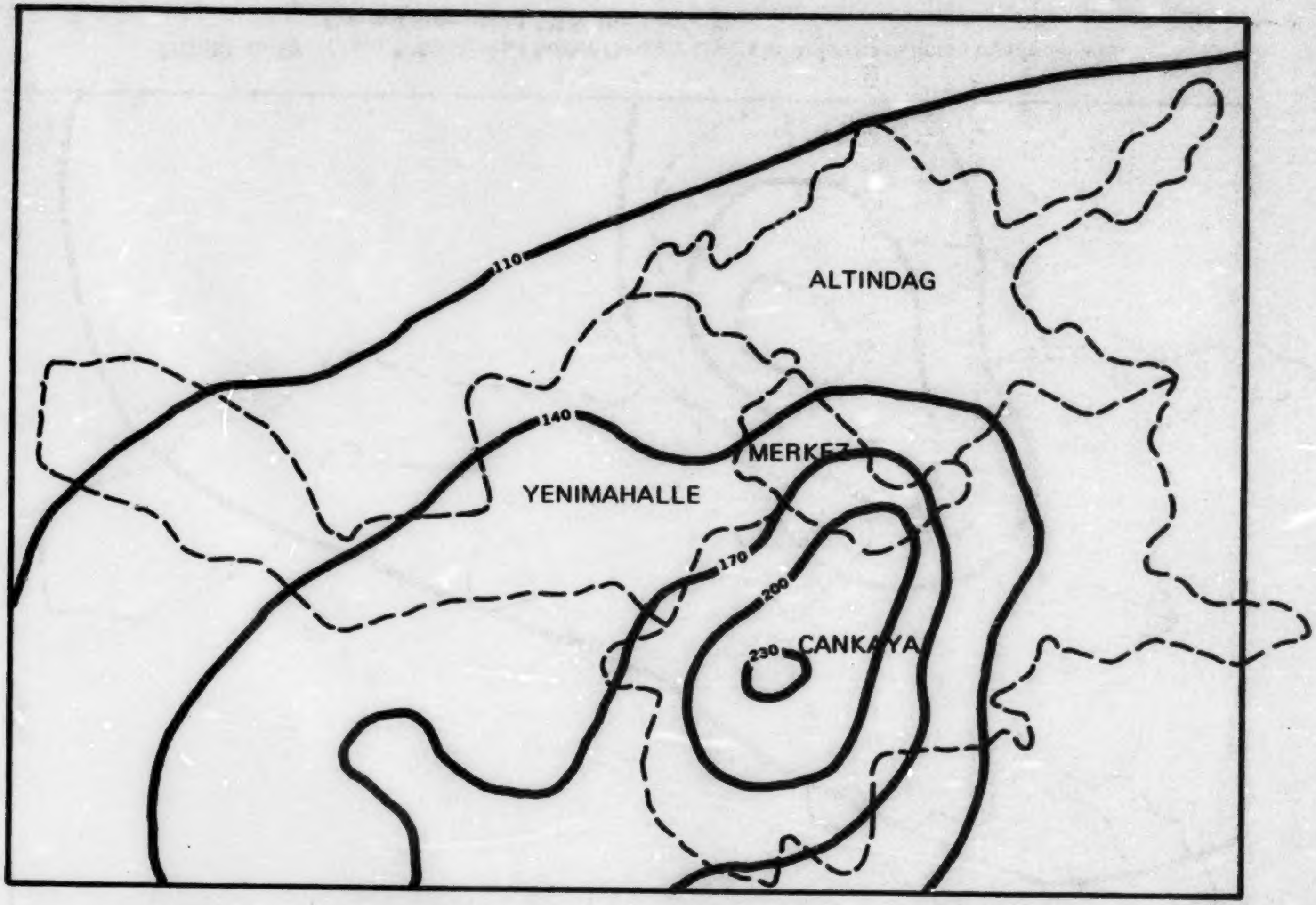

ALTINDAG
MERKEZ
YENIMAHALLE
CANKAYA
110
140
170
200
230

FIGURE A–51. Mean 1990 Annual Suspended Particulate Levels in Ankara Predicted by Model with Control Strategy of Briquetting of Coal for Household Heating ($\mu g/m^3$).

are achieved in other parts of the city, the effect in the outlying areas is less due to the expected growth of population and fuel use in these areas.

In the case of particulates the reduction is not as pronounced. The maximum concentrations are reduced by 20 ug/m^3. Because it was assumed that only fuels for home heating would be processed, the attendant decreases are much smaller than for SO_2 where all the fuels would be affected by the control tactic. It is important to note that these two tactics were chosen for illustration purposes only and do not represent the only alternatives available.

*U.S. GOVERNMENT PRINTING OFFICE:1972 514-168/55 1-3